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INVESTIGATION OF THE CENTRAL NERVOUS SYSTEM

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PART I

Investigation of the Central Nervous System Methods and Instruments

BY
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PART II

Atlas of Photographs of the Frontal Sections of the Cranium and Brain of the Rhesus Monkey (*Macacus Rhesus*)

BY
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ERRATUM

INVESTIGATION OF THE CENTRAL NERVOUS SYSTEM

By R. H. Clarke

On pages XLIV and XLV of the Atlas of Sections the named photographs are in correct order, but the untouched photograph XII has been wrongly put under the named XI and so numbered, and the untouched number XI is wrongly put under the named XII.

measurement of diameters of cranium.

Plate XI.—The whole rectilinear instrument, with inclined needle applied to cage, in 6th position.

Plate XII.—The whole rectilinear instrument, with horizontal needle applied to rear face of cage, in 7th position.

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INTRODUCTION

It is due to those who are interested in this work to express my regret for the delay that has occurred in publishing a promised description of a new stereotaxic instrument. Something in the way of excuse may be recognized in the following pages, when it is realized that the details explained, besides many which are omitted, had to be worked out, not only on paper, but in mechanical constructions which were submitted to experiment and modified in accordance with the results, involving much time, labor and expense.

One difficulty in constructing a complicated instrument is to secure the services of a maker who combines the requisite skill and appliances with leisure to carry out the work. The time of such men is valuable and they are not attracted by the uncertainty and difficulty of experimental construction. Such obstacles have been responsible for much delay; nevertheless, I had completed and tested an instrument and an illustrated description of it was ready for the press several years ago, but, at the last moment, the publication was postponed for the following reasons. The rectilinear instrument which is described and illustrated in these pages is constructed, as its name implies, on a rectilinear principle, and the movements of the needle, directed by guides, are controlled and measured by scales engraved on these guides or attached to them. To extend the range of these movements, to help the operator to avoid important structures in the brain and to reach any selected point by the most convenient route, or by more than one, the rectilinear movement was supplemented by an arrangement which provides for an inclination of the needle at various angles. But to direct it with accuracy, to know the exact position of the point at any inclination and at the same time, to make the required corrections for variations in the size of different heads, in three dimensions, was a matter of some difficulty. Calculations in the course of an operation are objectionable and I adopted a mechanical method of attaining these objects with a two-dimensioned indicator, which is figured in Plates XXV-XXVI and explained in Chapters III and IV. It soon became evident that an extension of this method to a

three-dimensioned indicator and a needle with universal movement would offer great advantages, but I did not see my way to a satisfactory design until after the machine referred to was finished, and though a good many parts of it are still retained, many modifications and additions were necessary, involving the construction of what is practically another instrument.

Now that both patterns are completed and can be compared, the advantage of the improved form will be recognized, though it may not supersede the previous one for all purposes. However, as these instruments are costly, I could not recommend anybody to purchase one with the probability of its being quickly superseded and I was obliged to defer the publication of the description till the last, and I hope, the final form was completed. It may be objected that there is no finality in these things, that the last pattern will suggest another and so on indefinitely. This is of course true of details which must always be susceptible of improvement until perfection is attained, but machines reach what may be called a final stage when they effect their object as well as can be reasonably expected, and such a stage may be claimed for the present instrument, which satisfies all reasonable requirements, and can be recommended to experimental neurologists for the investigations it has been designed to promote.

The rectilinear machine described here is the second of the kind which I have designed; some of my readers may have seen a description of the earlier one, in a joint paper with Sir Victor Horsley,[1] introductory to an unpublished account of an investigation of the cerebellum, for which it was employed. Since then, a few investigators have used similar instruments copied from it, for various parts of the brain, and in spite of mechanical defects and the disadvantage of applying it without a complete series of charts, with fairly good results. At the same time, it is no criterion of the method to employ it under these conditions and I have advised enquirers to wait for the new instrument and the earlier parts, at any rate, of the atlas of sections of the cranium of the cat and monkey, which Mr. Henderson and I are now publishing.

It is of course an advantage to be able to refer to sections in three planes, but a single series will furnish the essential data for directing the needle and with either of the instruments described here and the earlier parts of the atlas, any one will be in a position to undertake an investigation of the brain in the cat or monkey if he wishes.

The delay which has occurred, though unfortunate in some respects, has enabled me to introduce a few additions, which may enlarge the scope and utility of the method and will be described in this paper.

Those who have used the first instrument will find the later one a great improvement, but must not expect mathematical accuracy which is unattainable, as no animal's brain is constructed on such lines, but with a little practice and care he will find that he can reduce the inevitable error to small proportions.

Having reached something like finality in the evolution of the instrument I found it difficult to decide upon the alterations to be made in the description which had been completed to a certain point; much of it required to be re-written, but it was doubtful what to omit. If the cost of the earlier and the improved pattern were approximately the same, I should recommend the latter and be content with a short allusion to the first. I hoped to be able to append an approximate estimate of the comparative cost of the two machines, but this is difficult to obtain, because much depends on the number required, which it is impossible to predict, though the demand cannot be large, and I should imagine that the final instrument will cost two or three times as much as the rectilinear pattern.

As nearly all the essential parts of the first machine are used with the later improvements there is very little disadvantage incurred by getting the former to begin with and procuring the additional parts subsequently if required. There are many experiments for which the rectilinear machine serves very well and for such the plan suggested appears advisable. At any rate, it is desirable to give a full description of both instruments to enable the reader to draw his own conclusions, especially with reference to the work he proposes to undertake. To the descriptions and illustrations I propose to add directions for use and explanations which I hope will make the procedure sufficiently clear to enable the beginner to embark upon it without any special teaching.

Besides affording a substitute for mutilating operations, which are repulsive and not attended with results that justify them in the laboratory or hospital, a contingent advantage may be secured by facilitating the operative procedure essential to experimental investigation and enlisting the co-operation of medical men who are interested in scientific neurology, but have been deterred from supplementing clinical observations with experimental research by the want of special

training which they considered essential. For performing the operations required with the instrument it is not so, and the need of fresh workers in this field is urgent. Considering our ignorance of elementary anatomical and physiological data, the course and connections of tracts, the functions of large centers, not to speak of smaller but important nuclei, the vast amount of indispensable work requiring no exceptional skill, the fascination of the subject, and the harvest to be gathered, the slow progress from the dearth of investigators is deplorable. Certainly, there are no direct pecuniary inducements, but probably an increasing number of medical men would be willing to devote some of their leisure to these objects if they realized their importance and inducements.

In criticizing what appear to me defects in present methods of intracranial surgery, my observations do not in any way apply to the operators, who are called upon to act in circumstances which admit of no delay. They cannot wait for the improvements they may desire, but must make the best of such means as are available, whether they are satisfactory or not, and for imperfections in methods and means we must all accept a share of responsibility, as it has always been open to any of us to suggest improvements.

I had made arrangements for the publication of this work and the charts of the cranium of the rhesus in the *Journal für Psychologie und Neurologie*[8] in which the two first parts of the atlas (of the cat) have already appeared. But the outbreak of the European war arrested the progress of this arrangement, besides leading to the closure of the laboratory in which I have always worked and depriving me of the services of the instrument maker on whom I depended for the completion of certain small additions and alterations to the machine which are required.

PART I

Investigation of the Central Nervous System

Methods and Instruments

INVESTIGATION OF THE CENTRAL NERVOUS SYSTEM

METHODS AND INSTRUMENTS

By R. H. CLARKE, M. A., M. B.

CHAPTER I

A PRELIMINARY REVIEW OF THE SCOPE AND APPLICATION OF THE METHOD

The purpose of the method and instruments described in the following pages is to give such practical effect as may be possible to the principle of substituting mechanical for visual direction of needles and similar fine instruments for intracranial operations, whether they are required for anatomy, physiology, or surgery, in the hope of ultimately reducing to small proportions the mutilation which exposure of the structures of the brain entails.

Topography, Uniformity.—The topographical basis of the method depends on the measurement of structures from central section planes in three dimensions, determined by prominent anatomical features of the cranium. It is evident that, unless the position and relations of the planes, determined in this way, are reasonably constant, the method cannot be trustworthy. This objection is frequently raised and neurologists are not easily convinced of such uniformity of structure in the brains of different animals of the same species, nor in different men. Of the latter, I am not yet in a position to speak from experiment, as my work on this subject has been confined to the lower animals, especially the cat and rhesus monkey, but, within the limits of my experience, uniformity increases as we ascend the scale of cranial development and it would be a contradiction of the apparent rule if the relations of cerebral structures proved to be less constant in man than in the monkey or cat. The matter can be definitely decided only by the comparison of a large number of measurements and it would occupy too much space to produce even those which are available here; but the issue is fundamental and it is necessary

to offer sufficient preliminary evidence to encourage those who are interested in the question to put it to the proof of practical experiment, when they will find in their results the most satisfactory corroboration of the claim advanced. It may be mentioned, in the first place, that one of the greatest obstacles to the recognition of the evidence of uniformity is due to the prominent position and great interest attached to the convolutions of the brain. Every neurologist is impressed by their importance, familiar with the details of their arrangement and structure and appreciates their topographical value, but, at the same time, realizes that their regularity and symmetry are not constant enough for the requirements of accurate measurement and it seems at first very improbable that any part of the brain can be free from the defects he has so often observed in these structures. When, however, we consider the development of the pallium and that the convolutions are folds produced by the confinement of its extending area by unyielding walls, it may appear more remarkable that the irregularities are no greater and that the arrangement is generally as symmetrical as we find it. We could hardly expect that folds so produced would be constant enough to serve as bases of accurate measurement, nor should we anticipate that defects in their symmetry would furnish a criterion for estimating the degree of uniformity exhibited by the central structures of the brain. Rather, if *a priori* considerations have any weight, we should expect a marked difference and that, in an area which is the seat of extensive growth and expansion and subject to very considerable variations of size, the relations of parts would be affected to a far greater degree than in structures closely connected with the base of the skull, where growth is slow and comparatively slight, and variations are restricted to small proportions. Such a conclusion is strongly supported by the positive evidence of observation and measurement. It is most obvious in coronal sections where the symmetry of corresponding structures of the brain-stem to the median sagittal plane is remarkable and also of practical value, as this plane is one of the bases of measurement. Of all zero planes, it is the most easily defined and owing to the bilateral structure of the brain the most natural and obvious landmark. Anatomically, its position is marked, superficially and in deep structures, by numerous features which can be easily recognized and it can also be determined by bisecting transverse diameters through corresponding points on both sides of the cranium. Both methods can

be employed to corroborate one another, which, as a rule, they do. If there is any discrepancy, it is generally due to some difference, chiefly peripheral, in the development of the hemispheres and in case of doubt, for central structures at any rate, anatomical features, such as the raphé and the median division between corresponding points, are the surest guides. Such discrepancies, however, are neither frequent nor considerable, and the sagittal zero plane, determined in either way, is a satisfactory landmark for the brain stem and adjacent structures. Still more important and not less trustworthy, as a base of measurement, is the **interaural line**, passing from the center of one meatus to the other. The meatus is accurately centered by ear cones, which fit the conical ends of the ear pivots, and these are perforated in their long axis to serve as guides for the drill, which is used in the preparation of chart sections, to define the line. As the same ear cones and pivots are used to support the head in the frame for operations, and measurements are reckoned from the centers of the cones, the same line is defined for charts and operations by the same means. Thus, the interaural line defines the central intersection of the basi-horizontal and frontal zero planes; the distal definition of the former is determined by the lowest point of the lower margin of the orbit, and the frontal zero plane, perpendicular to the horizontal, extends from the same line to the vertex. The interaural line is, therefore, the focus and central zero of measurement, and as the principal structures of the brain which now require investigation are in its neighborhood, its accuracy is essential and far more important than the distal definitions of the zero planes, and, fortunately, in the cat and monkey it is a constant and trustworthy guide. I have drilled this line, through cones fitted in the meatuses, on both sides, in a very large number of cats' heads, and have been surprised at its regularity; as a rule, the drill grooves the free surface of the pons in the median sagittal line. The drills used were 14-wire gauge, 1.8 mm. in diameter, and on an average the depth of the groove is about half the diameter of the drill; but it is rare for the latter to perforate the pons without breaking its surface, or to pass without touching it. As the diameter of the drill is less than 2 mm., a variation of 1 mm. is sufficient to produce either of these results; hence, an error of 1 mm. is rare and a much greater one is not likely to occur in regions near the interaural line and measured from it, or from the frontal or horizontal zero planes which it defines. In the rhesus,

the interaural line traverses the pons about its middle; there is no definite feature at this point comparable to the free surface in the cat and slight variations cannot be recognized so readily, but, judging by measurements to neighboring structures, I believe it to be as constant and trustworthy a guide.

Thus, if adjustment of the ear cones is carefully conducted, in the central regions of the brain of both these animals, an error of more than 1 mm. is unusual and it is commonly less; hence, the bases of measurement are sufficiently accurate for experimental operations and it appears unlikely that they will prove less accurate in man.

Our object might be compared with that of a marksman, assuming that we are aiming the needle at a target with a 2 mm. bull's-eye. A good performer with a modern rifle considers that, if all circumstances are favorable, with the stipulated number of shots he may hope to score a "possible," getting somewhere on the bull every time, but that if the wind is strong, or the light bad, or he is at all unsteady, he will not be so fortunate. Similarly, although under favorable conditions, in a series of experiments with the instrument, an operator may succeed in getting the needle within a 2 mm. circle every time; nevertheless, a slight error of measurement or some defect of symmetry in an animal will spoil his average. Much, however, depends upon the weapon, and as with the rifle, so with the instrument, there is a good deal of difference between the old and the new.

Defective Methods.—We have sacrificed opportunities of progress in the anatomy, physiology and surgery of the brain, by too ready acquiescence in the assumption that we must remain dependent on the visual sense for every species of intracranial operation. Like many accepted convictions, its foundations are open to criticism and it is remarkable that its claims to credit have not been seriously challenged long ago.

Inaccessibility of the Brain.—It is difficult to imagine a region more inaccessible to vision than the deep structures of the brain. An organ of almost inconceivable complexity, not absolutely solid nor yet fluid, but exhibiting some of both qualities, slung on membranous supports, in an impervious bony capsule, which is never restored when once it has been destroyed to give access to the structures it protects, and in every part, bone, membranes and brain richly supplied with blood contained in vessels, of which some are inaccessible or difficult to control for the arrest of hæmorrhage. These conditions make it

impossible to expose the deep ganglia without serious mutilation, hæmorrhage and shock, which not only hinder the attainment of our object, but rob it of much of its value when it is secured. Instead of a clear view of the structures we find a stained and mangled mass, in which brain is scarcely distinguishable from blood-clot, landmarks are obliterated, structural relations confused and topographical precision impossible.

When we reflect on the extent of these difficulties we may well wonder, not that so little has been accomplished, but rather that so much has been achieved. We must recollect, however, that in the past there was a somewhat wide field for research in comparatively superficial structures, for the investigation of which our methods were fairly adapted and have been successfully applied. To-day, the richest ore lies in deeper levels where the difficulties are much increased and fresh obstacles must be overcome by methods adapted to meet them.

The Degeneration Method, Limitations.—Since the value of information regarding the course of fibers and their relations with cells, derived from the study of degenerations, has been realized, we must attribute to this source nearly every addition that has been made to our knowledge of the anatomy of the tracts of the central nervous system. These methods would serve us equally well and supply us with information of the same value in those regions which still remain unexplored if we could employ them; but their application is made impossible by the nature of the preliminary operations which are required. The same conditions have hampered the study of elementary functions by electrical stimulation, rendering its precise application difficult and depreciating the value of results observed in animals depressed by severe operations and prolonged and deep anæsthesia. So, while advance has been rapid in other directions, ignorance of the functions of the great centers of the brain persists. The largest of them is a silent desert of which our knowledge has advanced scarcely beyond the speculations of Dr. Carpenter of 50 years ago, and for the light which is at length beginning to break upon the functions of the thalamus we are indebted to the refined methods and indefatigable application of recent clinical investigation.

Similar obstacles confront the surgeon and bar his progress. Shock and hæmorrhage, imperfect repair of the protective coverings which are so indispensable, but must needs be destroyed, exfoliations, excrescences, tedious recovery, crippled faculties and a deplorable mortality

are too often the penalties of an injudicious enterprise upon an entrenched position.

Effects of Exposing Deep Structures.—We watch a trifling intracranial hæmorrhage which does not produce unconsciousness for hours or days and see a patient drift to death or become a helpless cripple and fold our hands, not daring to suggest the scalping knife and tomahawk, and, deprived of our first inspiration and last hope, complacently recommend the expectant attitude while the stream flows by. We cut away the laminæ, expose the cord and divide half a dozen posterior roots on both sides, to purchase a short respite from intolerable neuralgia, which soon recurs, but do not venture to discuss the prospects of section of a tract in the brain. Yet such operations are likely to be available in the future and in practised hands, with a 1 mm. needle and a 5 mm. trephine, may be scarcely more serious than the extraction of a tooth.

Removal of Tumors. Ferrier's Views.—Speaking a few years ago at Bath on the subject of operations for cerebral tumors, Sir David Ferrier[2] said he believed that he was the first to advocate operations on the brain nearly 30 years ago and that he took an active part in the first operation for the removal of a cerebral tumor which was performed by Mr. Godlee. He was perhaps more sanguine then as to the benefits likely to result from the surgical treatment of cerebral tumors, than the experience of the last 27 years had altogether justified. Only a relatively small proportion of cerebral tumors—from 7 to 10 per cent—were amenable to operation, and even this proportion would be reduced if one were to exclude from the operable category the diffuse tumors. The mortality, even in the operable cases, was very great and only a very small proportion of the patients operated upon could be said to have been cured in the sense of having been restored to complete health and usefulness. Desperate diseases, however, required desperate remedies.

The conclusion is not reassuring, indeed it is a counsel of despair for all but those who are satisfied with "desperate remedies" and are able to regard the cure of "only a very small proportion—7 per cent"—as a triumph of surgery. Nor can we encourage ourselves with any definite promise of improvement or hope of advance while we cling to the visual control of intracranial operations with all it entails.

More Promising Methods.—If our clumsy fingers are to unravel the mysteries or alleviate the disablements of the most exquisite instrument of which our imagination can conceive, it must be by a refined art informed by topographical accuracy not yet approached, aided by instruments whose delicacy and precision will tax our beggarly efforts at construction to their utmost limit, and inspired by a concern for the resources of the victim which will tolerate no scratch, nor jar, nor the waste of a drop of blood that any possible exercise of ingenuity can prevent.

Passing from such anticipations to the practical questions, what is to be the next step? What can we do now? The answer seems to be that the first essential is to ascertain the extent to which we can substitute mechanical direction and control of instruments for the guidance of the visual sense; or, to put it another way, carry out intracranial manipulations without the necessity of mutilating operations, problems of which these pages attempt to offer some sort of solution.

The rigid cranium, which so deeply resents the exposure of the structures it protects, is an admirable base for the direction of fine instruments. It presents landmarks, not perfect indeed, but reasonably satisfactory, supplies fixed points for measurement, and by completely enveloping yielding structures in an immovable frame, gives them a fairly constant relationship to one another and itself, highly favorable to the purpose in view.

Application to Anatomy and Physiology.—The principle of the mechanical direction of instruments on which the methods described here are founded, will probably commend itself so far as it is recognized to be practicable; the extent to which it will be applicable the future must decide, but in some respects its practical value is already assured. For intracranial anatomy, the most minute lesions, or larger ones if required, can be produced in any part of the brain with sufficient accuracy and trifling injury; it thus supplies the indispensable conditions for applying the degeneration method to every part of the brain and enables us to explore tracts and nuclei wherever we wish. The operative advantage may prove equally serviceable to physiology, for though our present methods of electrical stimulation are not capable of affording very much information of the functions of the central ganglia, we may look to the assured progress of electrical science to supply the deficiency and to infuse fresh life into this branch of research.

Application to Surgery.—In these departments of investigation we have had sufficient experience to speak with confidence of the value of the method, and those who require further evidence can now obtain it in the most satisfactory way by trying it for themselves. But from its application to animals for the objects described to its adaptation to human surgery is a long step, involving, in the first place, a laborious and costly investigation to construct the necessary charts of the human cranium. Possibly, two or three types will have to be represented by different standards, for each of which hundreds of millimeter sections in three dimensions must be cut and photographed. Before this work can be completed an amount of experience will have been collected from experiments on animals which will put the whole subject on a very different footing from that which it now occupies. For my own part, I have no doubt that its application to various purposes in human surgery will be only a question of time, and it will be a source of interest to those who work with the instrument to observe the directions in which the method may be profitably applied to the relief of disease, as well as extended in those fields of research with which it is more immediately concerned.

Physiological Excitation.—As already remarked, the present method of stimulating nerve centers with a faradic current and estimating the effect by muscular contractions is so inadequate for the investigation of central ganglia, owing to escape of current and the fact that many of these centers have no direct connection with a motor mechanism, that improved procedures are greatly needed. Modifications of the current may be found to offer certain advantages, but it is difficult to see how they can ever be entirely free from the same objections.

The stereotaxic instrument may possibly open a more favorable prospect by removing obstacles which have prevented the application to the brain of methods which have given definite results in the cord and nerve trunks. In the experiments recorded by **Gotch and Horsley** in 1891,[4] they found that, by stimulating the limb areas in the cortex of the cat or monkey with faradic currents, they produced very marked negative variations of the electrical current in the cut end of the cord at different levels and in the sciatic nerves. The changes were recorded by a galvanometer and, although slight variations occurred on the same side as the cortical stimulation, they were many times greater on the opposite side, where the impulses were conveyed by the pyramidal fibers following the course of the motor path.

It is reasonable to expect that similar stimulation of centers in the brain may produce corresponding changes in the course of tracts connected with them; with delicate galvanometers and suitable conductors it may be possible to demonstrate the existence and to measure the rate of transmission of such impulses and the amount of variation produced at different stations in the course of tracts in the brain.

So long as the application of electrodes to precise points in the brain entailed the necessity of exposing the latter by destructive operations, not only was it difficult to direct the electrodes and retain them accurately, but all the conditions were so much affected by the operation that it was hopeless to look for delicate electrical changes, or accept as normal phenomena any results which might be observed. These difficulties are now greatly reduced; we can introduce fine insulated platinum needles through small trephine holes to any required point and keep them securely fixed and connected with galvanometers, under conditions which may be regarded as approximately normal.

The conditions are of course very different from those met within the cord and peripheral nerves. The impossibility of isolating the tract must be a serious difficulty and may be insuperable. But the fact that the galvanometer records changes eight or ten times as great in the path as outside it, even when it is so near as the other half of the cord, encourages the hope that, by means of electrodes applied directly to the channels by which the impulses are conveyed, it may be possible to detect variations in the brain itself. And if such a result can be secured, the information might be so valuable that the subject deserves very careful investigation.

The technique of introducing and fixing insulated platinum needles sheathed in glass, for this or any other purpose, presents little difficulty.

The electrode, preceded by a pilot needle (Pl. XVI, I, 1) which perforates the dura, is introduced through a small trephine hole to the selected point. As the animal will not be kept alive after the experiment, the needle may be secured in position with cement which is softened by heat and hardens rapidly, such as white lead, plaster of Paris, and shellac. Or preferably, two or three thin celluloid discs, rather smaller than the trephine and perforated in the middle, are slipped over the needle before it is introduced; when it is in position each disc is fixed to the needle with a drop of hot shellac and secured in the trephine hole with equal parts of resin and beeswax,

applied with a brush; this cement is fluid when hot and sets very quickly.

If there is occasion to retain a needle longer, the nickel plugs shown (Pl. XXXV, II) should be used. These are easily sterilized, and nickel is not acted on by the tissues nor does it cause irritation. The plugs were designed to retain fine platinum tubes, 1 mm. in diameter, for draining off serous fluid or for the introduction of minute doses of drugs.

Drugs: Local Action.—It is possible that valuable information may be afforded by the direct action of drugs on brain centers and cells. If we consider the effect of minute doses of prussic acid or aconite introduced into the stomach, and the rapid onset of symptoms, it is obvious that, if the poison acts directly on the cells of the respiratory center, it must pass through the capillaries of the liver and lungs first, and be mixed and diluted with a large quantity of blood. But inasmuch as only a very small quantity of this dilute mixture can finally reach the cells themselves, the amount of the poison which produces the effect must be minute, and the susceptibility of the cells very remarkable. It is worth while making an attempt to ascertain whether any drugs applied directly to central nuclei will produce specific reactions, modify or arrest impulses, or produce changes in the cells themselves which can be recognized; for such results might be of value to the pharmacologist, as well as the physiologist, as a means of testing the properties of these drugs. The platinum tubes referred to are suitable for the introduction of minute doses of powerful drugs and there is no difficulty in dilating the small passage with split cannulæ for tubes of any size for medication, syringing or drainage.

There are one or two other appliances to which I will refer very briefly before proceeding with a systematic description of the instrument.

The varieties of the needle which may be developed in time for all sorts of intracranial operations are practically unlimited. We have made a beginning and illustrations are given of a spherotome (Pl. XVII, IV), designed by Dr. A. T. Mussen, and two or three forms of a cutting needle of mine. The instrument is a hollow steel needle, 1 mm. in diameter, which is just large enough to admit a steel wire and concealed watchspring knife which can be projected and withdrawn as required. In the horizontal cyclotome as seen in the figure

(Pl. XVI, II), after the needle has been introduced, the knife is projected horizontally from a slot close to the end of the needle. It can be projected any distance up to 4 mm. and a milled head and scale show how far it is extended. The whole needle is then revolved one complete turn, cutting a circular disc from 2 to 9 mm. in diameter, the knife can be retracted, the needle sent in a little further or withdrawn a few millimeters and another disc cut of the same or a different diameter. In this way, circular figures of different kinds, cones, cylinders, barrels of various sizes, can be cut by the introduction of a 1 mm. needle. It is preceded by the pilot needle and the track that is left is quite insignificant; there has generally been no trace of it after the animal has survived for three weeks, and I have not seen any hæmorrhage, except in trephining the bone which sometimes bleeds rather freely, especially in cats.

Section of Tracts.—This form of needle serves admirably for cutting tracts that are parallel to it, the operation being quite simple. In Plate II of the sagittal sections of the cat, in the atlas, the anterior column of the fornix, Vicq d'Azyr's and Meynert's bundles may be seen in sagittal lamella II. If we want to cut Meynert's bundle at the level of the mid-horizontal zero plane, the needle may be introduced in sagittal lamella I or III where they join anterior frontal lamella VIII, *i. e.,* 7.5 mms. in front of the frontal zero plane in the standard. After measuring the head, applying the instrument and exposing the bone by a small incision, the pilot needle is brought over the required point which is marked with ink or a drill, the needle is racked out of the way while a 5 mm. trephine (Pl. XXXV) is applied to this spot, the small disc of bone is removed, and when the bleeding has been checked the pilot needle is brought back and racked down through the dura and brain to the horizontal zero plane. It is removed and replaced by the cyclotome which is introduced to the same point, the knife is projected 1.5 or 2 mm. directly forwards or backwards, the position being known by a line on the milled head, the needle is then rotated through half a circle towards lamella II, the knife is retracted and withdrawn. The tract is found divided by a little incision about 3 mm. long. In the vertical cyclotome (Pl. XVII, VI) the concealed knife is pivoted on its center in the cleft extremity of a hollow needle like the last; when introduced, it lies in this cleft parallel to the needle. It can be rotated on its pivot to a right angle by a steel wire passing down the needle and pivoted near

the proximal end of the knife, which by this movement cuts two diagonal quadrants. It is then withdrawn by the wire to its original position, the needle is rotated through half a circle, and the knife again projected, cutting the other two quadrants and completing the disc, the plane of which is parallel to the axis of the needle.

In Mussen's spherotome (Pl. XVI, IV) a steel wire ending in a watch-spring knife is introduced into a hollow steel needle, wire, knife and needle being in the same straight line. One side of the needle near the point is filed away to expose a few millimeters of the watch-spring which lies flat, and at its termination is secured by a rivet in a slot close to the end of the needle. When pressure is applied to the wire the spring bulges in the form of a bow, the size and shape of which vary with the pressure applied. By a complete rotation it cuts a spheroidal figure, the size of which depends on that of the knife and the amount of pressure. It will be convenient for the complete resection of nuclei and possibly eventually for breaking up a bloodclot or eviscerating a tumor.

Electrical Resistance, Diagnosis.—The substance of the living brain offers a rather high resistance to the passage of electrical currents. It may be possible to utilize this quality for diagnostic purposes in the case of intracranial hæmorrhage, abscess, cysts and even tumors. If the double platino-iridium insulated needle used for stimulation is included in a circuit with a milliamperemeter, a rheostat and constant battery and introduced with the same current successively into brain substance, muscle and fresh blood, it is generally easy to distinguish them. If the meter records 1 ma. for brain, it will read about 3 ma. for muscle and 8 to 10 for fresh blood. There is some variation due to polarization and also to the condition of the tissues, the amount of fluid they contain, etc., and when blood coagulates its resistance is a good deal raised. Further experiments are required to ascertain how far the results can be depended on.

Kohlrauch's Method.—The above arrangement is a rough one and Kohlrauch's method with an alternating current and coil, a Wheatstone bridge and telephone, is much more delicate and is free from the risk of polarization which cannot be avoided with a constant current. Employing this method, with prepared platinum needles insulated in glass up to their points, which are 1 or 2 mm. apart, I repeated the experiments mentioned with Mr. W. L. Syme in Professor Waller's laboratory and they entirely corroborated the previous

results. The apparatus gives a direct reading of the resistance in ohms and we tested various tissues and organs as well as brain and blood. The principal results were as follows: Needle points 2 mm. apart and about 2 mm. exposed, platinized black and heated, direct reading:

Saline solution	Resistance	150- 180	ohms
Fresh blood in heart	"	300	"
Fresh blood elsewhere	"	300- 400	"
Clotted blood	"	400- 500	"
Muscle	"	500- 600	"
Brain *	"	1200-1800	"

The telephone, though very delicate, is not so convenient as a galvanometer where fluctuations of resistance are followed by sight. This is a great advantage not only because it is quicker, but also because the resistance and its variations can be observed while the needle is being slowly racked through the brain. With the telephone, to ascertain the resistance at any point the needle must be stopped and the slide on the Wheatstone bridge adjusted till the telephone is silent when the resistance can be read on the scale. This not only involves more time and trouble, but may be a source of error. Owing to the amount of blood and fluid in the brain a small quantity may collect round the needle when it is stationary and the resistance of the brain appears to be that of the fluid in which the needle is bathed. When the latter is moved on a short distance the resistance increases and the error is detected; and when the needle is kept slowly moving, the accident is not likely to happen. It will, therefore, be an advantage if some graphic method of recording the resistance can be substituted for the telephone. In any case, it seems probable that the method may be of some practical use.

Trephining.—For introducing a needle into the brain a very small trephine about 5 mm. in diameter is sufficient. It should be fitted to a dental engine or a motor and have an adjustable stop. With the ordinary dentist's holder it can be quickly changed. A center pin is only necessary when we require the needle to be exactly in the center of the trephine hole; in that case, the best plan is to use one till a groove is cut and then substitute a trephine with a stop and no center pin. Unless the opening is over a sinus one need not cut the dura. It can be penetrated by the pilot needle, which should be passed down to the

* White matter of brain about 200 ohms higher than grey (cortex).

required point and then withdrawn, after which the insulated or other needle is passed down the same track. The pilot needle penetrates the brain with less injury than the others; it will perforate membranes if necessary; is not liable to be deflected and should generally be employed.

Arrest of Hæmorrhage.—Hæmorrhage from the small trephine holes may persist for some time and be rather difficult to control without a special appliance. Wax or paraffin are not very satisfactory, as the trephine hole is too small to admit the finger and it is difficult to apply these materials with an instrument to the edge of the diploë, close to the surface of the brain, when the structures are not visible. The effect of the anode in producing rapid coagulation of the blood may be turned to account and an insulated trephine and copper ring will stop the bleeding in two or three minutes, but a self-retaining galvanic plug (Pl. XXXV, I) is more convenient. An overlapping metal collar, rather smaller than the trephine, is fitted over a segmented ivory ring and expanded by a cone drawn outwards by a small screw; when introduced into the trephine hole the collar can be pressed against its circular edge. The plug is connected by an ivory bridge with a hollow copper ring, grooved on its under surface and packed with wool moistened with saline solution. The ring, which is rather larger than the plug, is kept in contact with the bone by the ivory bridge and a small screw exercising counter-pressure against the expanding plug; it is connected with the anode and the metal collar with the cathode, the whole being self-retaining and easy to apply. The leads have been attached previously and directly the crown of bone is removed the plug is introduced and fixed. Three milliamperes are sufficient, but it is advisable to begin with one and increase it. The plug stops the bleeding at once mechanically and, if retained two or three minutes, arrests it altogether. I have had a pair of expanding forceps made for the application of wax or paraffin which may save time and be preferable, in some respects, to a galvanic current.

Many other possible applications of these methods and instruments to cranial surgery will suggest themselves; at present they must be speculative, but some of them are likely to be worth consideration and experiment. Except in a few carefully selected cases, the consensus of present opinion is adverse to the ablation of cerebral tumors by the usual methods and it is improbable that any improvements in technique, on similar lines, will give much more satisfactory results,

inasmuch as the principal defects are inevitable. If any of the numerous methods of treatment which have been tried or recommended for inoperable tumors should be attended with more success in the future than in the past, the brain is a more favorable region for their application than most parts of the body. Its soft homogeneous structure, insensitiveness, the absence of large vessels and nerve trunks in most of it, its tolerance of small lesions, such as those produced by electrolysis or the passage of needles, the facility with which needles can be directed with the instrument to selected points at measured intervals, are obvious advantages. Numerous punctate or linear electrolytic lesions are well borne and can be very precisely limited. The margins of electrolytic lesions, examined microscopically, are seen to pass abruptly into apparently healthy structure and when a small electrolysis is effected by an insulated needle in an excitable area, if the needle is advanced 2 mm. immediately afterwards and a faradic stimulus applied, it elicits a normal response, showing that the adjacent structures are scarcely affected, even momentarily. Experiment may show the possibility of utilizing such electrolytic lesions to arrest new growths in the brain by cicatricial contraction and it might be expected to have more success in this region than elsewhere, especially if the lesions were produced at measured intervals, representing the nodes of a reticular arrangement enveloping a tumor. The introduction of tubes or needles of radium, the injection of serum or other organic fluids, astringents or alcohol, present no difficulty and what has been said of the possibility of improvement in the diagnosis and, therefore, the treatment of hæmorrhage would be equally applicable to abscess or cysts. The stereotaxic method and instruments are applicable to such purposes and indispensable for most of them. The whole subject offers a promising field for study and investigation.

CHAPTER II

THE STEREOTAXIC METHOD

Essentials, Topography, Zero Planes and Landmarks, the Horizontal Zero Plane, Correction of Variations of Size, Preparation of Charts and Sections, Proportional Scales

It appeared desirable to begin this description with an explanation of the scope and objects of the stereotaxic method in its more or less evident application to various practical purposes, because, when exhibiting the instrument, the first questions asked me have been, "What is the use of it?" and "What is the advantage of introducing a needle into the brain?" The experimental neurologist does not require to ask those questions, but for everyone the interest of the matter must depend a good deal on the ends he has in view and the probability of their attainment. I have, therefore, endeavored to meet enquiries of that kind at the outset by a superficial and in some respects speculative review of the subject which we must now proceed to examine in detail. The stereotaxic instrument is only part of a method which includes a system of topography and a series of charts without which the machine would be of little value. This has been explained in the first part of the Atlas of Sections which was published in the *Jour. f. Psych. u. Neur.*[*] and which some of my readers may have seen. Others, however, may not have done so, or may have forgotten, and it is so inconvenient to be referred for essential details to some work or paper which is not at hand, that it is advisable to introduce a short explanation sufficient to make subsequent reference to the subject intelligible.

The essentials of the method are:

1. A system of topography by which the cranium can be divided into minute areas which can be readily identified and recorded.

2. The stereotaxic instrument for directing a needle by graduated movement in three planes to any point in the cranium.

3. A series of scale photographs of sections of the frozen cranium, 1 mm. thick, in three planes, to identify and localize any given point so that the instrument can be adjusted accordingly.

4. A method of correcting variations in size in three dimensions applied to both charts and instruments.

Topography—It is not practicable to make accurate measurements from the irregular curved surface of the cranium, but any point can be localized by rectilinear measurement from central section planes determined by prominent anatomical features. With this object the cranium is divided into eight segments by three sections, each of which is perpendicular to the other two, and approximately median in relation to important structures. They are termed sagittal, frontal and horizontal, and the diameters of the cranium perpendicular to these planes, transverse, longitudinal and vertical, respectively. The eight segments into which the cranium is divided by these sections are described as right and left, frontal, temporal, occipital and cerebellar. The three internal surfaces of each segment are those of a cube, and any point in a segment can be identified by three perpendiculars of correct length dependent from them. Measurements are made from both sides of each section plane which counts as zero.

The position of the section planes is determined as follows:

Section Planes.—A line is drawn from the center of the auditory meatus, determined by a cone, to the lowest point of the lower margin of the orbit on each side. This is the *basal horizontal zero plane.* It is almost entirely below the brain, and to secure the advantage of measurement from both sides another horizontal zero plane is constructed above, but parallel to it. The distance above it is empirical, determined by convenience, and varies with the species of animal employed. In the monkey, it is one-quarter of the distance from the center of the meatus to the vertex, on a line perpendicular to the horizontal plane; in the cat it is one-third and in the hedgehog one-half of this distance, the difference depending on the relation of the interaural line to the brain in different animals. In the above instances the proportions given have the effect of bringing the upper line to something like the same distance, *viz.,* 10 mm. above the meatus with approximately similar relations to the orbits. A frontal section carried down the line referred to from vertex to meatus is the frontal zero plane, while the sagittal zero plane, as already stated, is the median sagittal section of the cranium, determined by transverse measurement through corresponding points on both sides and by well-marked anatomical features.

Charts. Records and Reference.—The charts are photographs of serial sections of the frozen cranium 1 mm. thick, sawn parallel to each of the three zero planes. In each section, lines representing the other two zero planes are drawn by marks for which the cranium has been drilled before it was fixed in the saw. The slices are called lamellæ, and are numbered from both sides of the zero plane to which they are parallel, the number of a lamella indicating the number of millimeters from the zero plane in the standard. For the purpose of reference the lamella, or the photograph, may be divided into square millimeters by lines parallel to the two zero lines mentioned. The vertical lines (abscissæ) being indicated by numerals, the horizontals (ordinates) by letters of the alphabet. They are counted, like the lamellæ, from both sides of the zero plane. So, by mentioning the segment, the lamella and a letter and number, any cubic millimeter is at once identified and its distance from the three zero planes being conveyed by the same indications, the requisite data are furnished for directing the needle with the stereotaxic instrument.

The above is a short summary of the method of topography of which a description was given in the first part of the Atlas.[5] It is advisable to add some further explanation of a few of the details which have been alluded to, such as the reasons for selecting the present zero planes and adopting two horizontal zeros, corrections for size and proportional scales, and the preparation of charts and microscopic sections. Some of these points will be more fully discussed in another chapter, but a short explanation will meet certain difficulties which may suggest themselves at this stage.

Zero Planes and Landmarks.—With regard to the position of the central zero planes and the anatomical structures by which they may be determined, one, the median sagittal plane, may be considered obvious, being the natural division of the cranium and brain into symmetrical halves. The median plane can be determined by measurement, by bisecting transverse diameters drawn through corresponding points on both sides of the cranium and by various anatomical structures which indicate the median line, sutures, raphés, commissures, etc. These indications generally agree and if there is any discrepancy it is usually slight. When a defect is appreciable, for the localization of a structure, the anatomical guides are to be preferred, as there may be a defect of symmetry evident by measurement of the

whole transverse diameter of the cranium without affecting the relation of many corresponding points within the brain to the raphé which lies between them. In the selection of the horizontal and frontal zero planes there is room for difference of opinion, and the lines and landmarks most suitable for cranial topography have been thoroughly considered and discussed by anatomists. In some cases, like that of the Frankfort-Munich plane, points selected, *e. g.,* the upper border of the external auditory meatus, may be applicable only to bones or dried preparations and not available for our purpose. Again Chiene's, Grünbaum's and Sherrington's divisions are mainly designed for superficial structures, convolutions and sulci and the meningeal vessels. But what is sometimes called Reid's line from the lowest point of the lower border of the orbit to the center of the external auditory meatus (auricular point), which can be determined accurately in the living subject by a cone, is a well-defined constant and has been adopted as the base line or basi-horizontal zero plane.

Selection of Zero Planes.—It may be objected that a line drawn from the upper margin of the orbit to the center of the meatus corresponds more closely to the base of the brain and is preferable to the one selected. Anatomically it would have advantages and might have been adopted, but there is a practical objection depending on the application of the machine. It is necessary that the frame or head-vice, which is the horizontal zero of the instrument, should coincide with the horizontal zero of the head and, as the machine is too heavy to be supported by the animal's head, it is suspended from horizontal cross-bars, rotating on a central pivot, by four springs which afford complete support without interfering with free movement in every direction, which is essential in stimulation experiments. When the head is fixed so that the present base line coincides with the upper border of the frame and suspended as described, the observer has a good view of the whole face, which is essential, the eyes and mouth being especially important; but if, under the same conditions, the frame is made to coincide with the line from the upper border of the orbit to the meatus a good view of the face is not obtained, a defect with precludes the adoption of this line. On the whole, the lower margin of the orbit appears to be the best level for the basi-horizontal plane and the frame is fixed so that its upper border coincides with it; and as this is the horizontal zero of the instrument from which the scales for vertical measurement are graduated, it

follows that for directing the movements of the needle for operations and for measuring and comparing the vertical diameters of heads it is most convenient to reckon from this line. But it has also been mentioned that in order to secure the advantage of measuring from both sides of the zero line another horizontal zero which may be called the mid-horizontal, about 10 mm. higher, has been adopted as a standard for general topographical purposes. This appears to introduce needless complication and requires explanation. With the first instrument the mid-horizontal line was adopted as the horizontal zero for all purposes. One of the principal reasons for selecting it was mechanical necessity, as the clamps employed at that time were not very satisfactory and this was the only level where the horizontal frame could be fixed securely, resting on the bridge of the nose with its lower border at the level of the inner canthus bisecting the vertical diameter of the orbit. This may be regarded in a sense as a "natural" position in both the cat and monkey, for if the frame is fixed a little above or below it, unless it is very secure, it works back to this level. With improved clamps the frame can be secured with its upper border level with the base line, bringing the frame about 20 mm. lower in relation to the head than the position in the first machine. There is a decided advantage in the lower level, inasmuch as, the cage and stage being easily removed, the whole head is freely exposed for shaving, trephining, dressing, etc., and the range of the needle is much increased. An objection to making the mid-horizontal line the principal or only zero is the absence of anatomical points to determine it. The inner canthus or the center of the vertical diameter of the orbit may serve for one, but there is nothing posteriorly except a measured distance from the base line or the meatus; and, since the vertical diameters of different heads vary, if the mid-horizontal line is to maintain the same relation to the base line and vertex, as it must, its height above the base must be a constant proportion and not a fixed number of millimeters. For this reason, the proportions of one-quarter of the vertical diameter in the monkey and of one-third in the cat were adopted and after measuring the head the frame had to be adjusted accordingly before it was fixed. In both animals the lower border of the frame came to the level of the inner canthus about 10 mm. above the lower margin of the orbit and the center of the meatus. This level was adopted for measurements of the instrument, for transverse and longitudinal gauging and drilling of the cranium,

as the horizontal zero plane for segmental division and topography, and for record and reference in notes and descriptions. But the adjustment of the frame after measuring the head required a special mechanism at both orbital and aural attachments which complicated the instrument, wasted time and furnished sufficient reason for adopting the simpler and more satisfactory arrangement now in use.

These considerations appear to suggest the advisability of abolishing the mid-horizontal line altogether and adopting the basi-horizontal line as the horizontal zero for all purposes, but unfortunately there are some for which it is unsuitable. In the first place, it does not serve for longitudinal and transverse measurements of the cranium. It is desirable that these should always be made at the same level through corresponding points; the mid-horizontal plane serves the purpose, although the maximum diameters are a little higher, but the maximum points are not absolutely constant and not much greater than those at the mid-horizontal plane; and if measurements are always made at this level they probably give as trustworthy indications for the estimation of relative size as elsewhere. Again, the basi-horizontal line falls below the greater part of the brain in both the cat and monkey, and if it is employed for segmental division, the advantage of measurement from both sides of it is sacrificed and the cranium is divided into four segments instead of eight. This segmental division is a useful one topographically, especially for affording a method of recording by a short and convenient reference any cubic millimeter in the brain in notes and descriptions and assisting the mental reconstruction which is desirable.

Two Horizontal Zeros for Different Purposes.—A review of the foregoing considerations leads to the conclusion that both the basi-horizontal and mid-horizontal planes have their own special advantages, each one fulfilling certain indispensable requirements which cannot be met by the other, and that the only practicable solution of the difficulty of selecting one of them as the horizontal zero plane is to retain them both, employing them for different purposes. It is essential that the basi-horizontal line, the only one which can be directly defined by precise anatomical landmarks, should coincide with the frame, which is the horizontal zero of the instrument, and thus form a common zero from which vertical measurements for estimating variations of that dimension in different heads are made and the movements of the needle directed. It is equally necessary that a higher level, the

relative position of which is constant, should be adopted for drilling and gauging in the transverse and longitudinal diameters and for segmental division for topographical purposes and reference, and the mid-horizontal line, as described, is the most suitable for these purposes. The objection that the adoption of two horizontal zeros may lead to confusion, even if well founded, cannot compare in importance with the positive advantages enumerated; and it does not seem probable that when the different objects are clearly recognized, there will be any difficulty in keeping these purposes and the zero planes which serve them distinct and the use of the terms basi-horizontal and mid-horizontal facilitates the distinction. Both lines are shown in the atlas of photographs of sections of the brain of the rhesus monkey prepared by Henderson and myself and published with this description.

Corrections for Variations of Size.—The topographical divisions described would be very simple if the heads of the same species of animal were always the same size in all dimensions, and the chief difficulty encountered is in adjusting the divisions and measurements to the variations in three dimensions which must entail corresponding variations in either (1) the number or (2) the size of the divisions. We can take our choice of these alternatives and there can be no question that the latter is to be preferred. It is important that each lamella should always contain the same structures and that a reference should always mean the same thing; hence, the number of divisions must be constant and their variation in size must be accepted and regulated by the use of proportional scales. If a cranium of average size is adopted as a standard in which the units of measurement are millimeters, when the dimensions are greater or less than in the standard, the units are coordinates bearing the same proportion to millimeters as the whole dimension does to that in the standard; in other words, all heads are reduced to the common measure of the standard for that species in all dimensions and the units of measurement, whether millimeters or coordinates, are regarded as millimeters. This method is followed in the construction of charts. The heads from which the sections are cut vary in size, they are measured and the necessary corrections made to reduce them to the standard in all dimensions. The number of lamellæ in each dimension is always the same, but their thickness is varied by regulating the saw with which they are cut by a proportional scale which is set to measure millimeters or more, or less, as the whole dimension is of standard size, or more, or

less. The square millimeters, into which every lamella in the standard is divided, are modified in the same way and a corrected scale, proportional to the two dimensions of the selected head represented, is furnished with each photograph and employed, instead of millimeter scales, to measure the distance of any point in the section from the zero lines. After the selected head has been measured, before it is removed from the gauging and drilling cage, the position of the zero plane is marked on the surface and the cranium is drilled at three points perpendicular to the plane of the proposed sections. One puncture is at the intersection of the two perpendicular planes and the other two 10 mm. on each side of it in one of these planes. The punctures of the drill appear as dots in every section and with their help the crossed lines representing the zero planes perpendicular to it can be defined. A needle is left in the central puncture and is used to adjust the head accurately in the vice of the saw. Heads are kept till sufficiently stained and hardened in formalin 5 per cent and potassium bichromate 2 per cent. They are then frozen in carbonic acid snow and adjusted in the vice of the saw; the scale of the saw, which is composed of silk threads, is set in accordance with the measurements of the dimension to be cut, the intervals being actually or approximately 2 mm. With the saws now used little more than .5 mm. is destroyed by each saw cut and the slices are therefore nearly 1.5 mm. thick. Each slice represents two lamellæ and both surfaces are photographed. Scales are prepared corresponding to the diameters of the crossed zero lines and attached to the photographs.

Microscopic Sections.—It is an advantage, especially for students, to carry out the same topograhical methods in the preparation of microscopic sections, for in this way the localization and description of lesions and degeneration are facilitated. Sections should be cut parallel to one of the zero planes and the division into the standard number of lamellæ for each dimension maintained. The procedure is described in Chapter VI.

References and Records.—It has been mentioned that any cubic millimeter in the brain can be identified and recorded by a simple formula giving the segment, lamella and the number of millimeters, or coordinates, between the given point and the zero lines of the lamella. To distinguish the latter, letters of the alphabet may be employed for the vertical units and numerals for the horizontal. This is applicable only to sagittal and frontal lamellæ. If they are hori-

zontal, the zero plane must be distinguished by a letter *T* or *L*, for transverse or longitudinal. But as it is very easy to transpose the indications for one dimension to another, it is best to make all references in the sagittal plane and, if that is understood, the word sagittal may be omitted. Left frontal segment, (sagittal) lamella VI, b4, indicates a cubic millimeter, 6 mm. to the left of the sagittal, 2 mm. above the mid-horizontal and 4 mm. in front of the frontal zero planes, respectively. As comparatively high numbers and still more late letters of the alphabet are more difficult to follow than the earlier ones it may be convenient, when high numbers are involved, to divide the surface of each lamella into 5 mm. squares, called divisions or blocks, distinguishing the vertical ones by capital letters and the longitudinal by Roman numbers, the small letters and the ordinary numerals being still retained for single millimeters or coordinates. Thus *Dc* would represent 23 mm. or coordinates vertically and III 2, 17 mm. longitudinally.

Proportional Scales.—Two kinds of proportional scale are employed and fully described in a later chapter. The most accurate form is constructed of parallel silk threads stretched between equidistant pegs arranged on opposed sway bars, the inclination of which approximates all the threads and diminishes the spaces between them equally. It is perfectly accurate, although not always applicable, but is employed with the saw and with the indicator, which will be described presently. In the rectilinear machine, however, where the movements of the needle in three dimensions are directed by scales attached to the instrument this form would be too cumbersome, and a proportional scale (pl. IX) is employed, consisting of a spiral spring enclosed in a tube, one side of which is cut away to expose the spring, whose spirals are units of measurement. When relaxed, the spirals are rather less than 1 mm. apart; by a slight extension of the spring, which can be fixed anywhere, the spaces measure millimeters or more, and with a little care in adjustment are sufficiently accurate though not equal to the silk threads. However, for the purpose required, an error of a small fraction of a single millimeter is not important, but a cumulative error which may sum up in a whole dimension to several millimeters is serious and such a risk is completely prevented by the spring scales.

Gauging of Cranium.—The first proceeding in an operation on a selected animal is to apply the gauging and drilling cage and take

the measurement of each dimension, from the central zero plane to the parallel surface of the bone, with the needle gauge. The points of measurement correspond to the three zero planes; the dimension recorded being perpendicular to one and parallel to the other two and taken at the point of intersection of the latter. The measurement of each dimension is compared with the standard and the proportional scale used for that dimension is set accordingly. The number of divisions of the proportional scale is, therefore, the same as in the scales of the chart and both are regarded as millimeters, although in reality neither of them may be millimeters and they may not measure the same. But they are treated as identical and all movements of the needle and measurements of selected points regulated by them, the result being the same as if all the heads selected were of standard size in all dimensions and the units of measurement were millimeters.

The following are the dimensions of the standard cranium of the rhesus which have been adopted in accordance with the method for the chart sections of the atlas for which all measurements were made with the needle gauge in the special cage shown in Plate XXXIV.

Longitudinal diameter: Prefrontal, 50 mm. Postfrontal, 30 mm. Total, 80 mm.

Transverse diameter: Right half, 30 mm. Left half, 30 mm. Total, 60 mm.

Vertical diameter: Supra-horizontal, 30 mm. Sub-horizontal, 10 mm. Total, 40 mm.

Longitudinally the prefrontal dimension extends in the median sagittal line from the frontal zero plane to the glabella. The post-frontal from the same zero plane to the occipital protuberance (inion).

Transversely each half is measured laterally from the sagittal zero plane to the point of intersection of the frontal and mid-horizontal zero planes on the surface of the cranium.

Vertically, the lower quarter extends from the mid-horizontal zero plane to the interaural line; the upper three-quarters, from the same zero plane to the point of intersection of the sagittal and frontal zero planes on the vertex.

The figures given are very near the average of a large number of heads that have been measured and are fortunately very convenient numbers for comparison.

In the paper in *Brain* previously referred to[1] the average dimensions of 32 heads of the rhesus were given. They differ slightly from

the above, but the discrepancy is very slight and is due to improved methods of measurement which are now adopted. If the two sets of figures are compared, it will be seen that in the vertical diameter they are the same. The total longitudinal diameter is 80 mm. in both, but differently divided; in the paper, the prefrontal and postfrontal divisions are given as 47 and 33 mm. instead of 50 and 30 mm. as above; and the transverse measurement is 32 mm. on each side or 64 mm. altogether instead of 60, a difference of 4 mm. in the whole dimension. The explanation is that in the first place the measurements in *Brain* were made with calipers and included the skin, and secondly they represented the maximum transverse diameter, whereas now they are always taken with the needle gauge to the surface of the bone and between the same points, *viz.*, the intersection of the frontal and mid-horizontal zero planes on each side, and this is generally not quite the maximum diameter as already explained.

The difference in the longitudinal measurement is also due to an improved method. Formerly it was made with calipers from the anterior termination of the mid-horizontal line a little below the nasion to the inion, including the integuments, which in the latter region are rather thick. The needle gauge, penetrating to the bone, makes the posterior measurement from the frontal zero plane to the inion rather less; but in front, measuring in a cage between perpendiculars, we consider the glabella, which is the most prominent point of the cranium, the best feature for the purpose. The result is that the anterior longitudinal dimension is rather more, the posterior rather less than the former estimate, but the total diameter is the same.

CHAPTER III

STEREOTAXIC INSTRUMENTS

Directing Mechanism, General Description, Principles and Requirements

Principles.—We have now to consider the mechanical direction of some form of needle or fine instrument to any desired point in the cranium. The position of the three zero planes and the method of determining and expressing their relation to any point have been explained and the principle of the required mechanism may be defined by a few self-evident propositions:

1. If we know the distance of a given point in the cranium from each of the three zero planes and can direct a needle to any required distance from these planes, we can direct it to the given point.

2. There is no mechanical difficulty in constructing a needle-carrier fitted to rectilinear traversing guides, or to an equatorial, like that used with an astronomical telescope, either arrangement being so disposed in relation to three central, mutually intersecting planes, each of which is at right-angles to the other two, that, within the limits of its excursion, the needle can be directed by graduated movements to any point of known distance from the three planes.

3. If we fix the head in such a structure so that the three zero planes of the cranium and instrument coincide, the needle can be directed to any point in the cranium of known distance from its three zero planes.

Requirements.—Assuming the accuracy of these principles, the next consideration is the most suitable instrument to give them effect. As with most mechanical contrivances, we are confronted with various practical difficulties, the solution of which is often a compromise, advantages in the one direction being purchased by sacrifice in another; and the most efficient instrument may not be worth its cost, compared with a cheaper one. The instruments here described have been evolved by attempts to solve these problems and, as far as they go, are a practical answer to questions respecting the nature and relative importance of the principal requirements, of which the following may be enu-

merated: Accuracy of adjustment and measurement; scales which register the position of the needle, or similar instruments, in all circumstances without involving calculation; speed and simplicity; adequate rigidity; provisions for introducing and changing various forms of needles for cutting, electrolysis, or faradic stimulation and arrangements for correcting variations of size of different heads in three dimensions; electrical connections are also necessary for directing constant or faradic currents through the needle by different routes. In the descriptions and illustrations the reader will recognize the purpose of numerous contrivances, draw his own conclusions as to their adequacy and perhaps see his way to improvements.

Present Instrument: Two Patterns.—Three stages may be noted in the development of the instrument in its present form. In the first, the movements of the needle are entirely rectilinear and are measured directly by millimeter scales engraved on the guides of the machine or attached to them. The next step was to supplement the rectilinear movements and give a greater range to the needle, by providing for its inclination at various angles, but only in one plane and in one direction in each position, of which there are seven. These inclined movements are measured and regulated and the corrections for size effected by an indicator of either two or three dimensions; while in the latest pattern universal movements of the needle, from any position, are secured by fitting it to a form of equatorial and all movements and corrections for size are determined by a three-dimensioned indicator. The range and flexibility of the needle have been much extended and the utility of the instrument increased by the introduction of indicators of two or of three dimensions; they will be fully described and illustrated in their place, but some account of them will be given in this chapter. Direct measurement of inclined or universal movements of the needle, out of sight, and with necessary corrections for variations in the size of different heads, was not found practicable, but a satisfactory alternative is obtained by reproducing an exact representation of the mechanism by which the needle is directed to an objective in the cranium, at a given distance from its three zero planes in another instrument, the indicator, where the structures are visible and the needle can be guided by sight to an index point at the same distance from three coincident index planes and the movements repeated by corresponding scales in the machine which contains the head. This method has great advantages, but for simple

rectilinear movements a cheaper instrument can be employed. For such movements no indicator is required, the rectilinear machine is sufficient and is much less expensive than the complete instrument with equatorial and indicator. This machine cannot therefore be considered obsolete and I propose to give here a short general account of it and the methods of measurement adopted, followed by a similar description of the inclined needle adapted to this machine and the two-dimensioned indicator by which its movements can be regulated, and finally, of the equatorial and three-dimensioned indicator. This description will supplement and not supersede the detailed account of all the instruments which will follow and, although it involves a certain amount of repetition, it will make the subject more intelligible to begin with such a general survey. The complete descriptions of all the instruments which it is necessary to introduce contain a number of details which it is tedious and confusing to follow before their objects and mutual relations are recognized, but if the reader obtains a general impression of the nature and objects of the various instruments and the method of using them, he can then follow the detailed descriptions as far as he pleases.

Frequent reference has been made to corrections for size, which is an indispensable consideration with any form of instrument, and as the problems it raises and the provisions for solving them must be frequently encountered, it will be convenient to discuss them first.

Corrections for Size.—If the heads of animals of the same species were all the same size, the application of the foregoing principles would be simple. We need only prepare a series of charts of the cranium of the selected species, from sections 1 mm. thick, in one or more planes, photographed to scale, with crossed lines indicating the other two zero planes in each chart, to enable the operator to ascertain the distance of any point from the three zero planes and direct the needle by those measurements to reach the same point in the head, already adjusted and fixed in the machine. But as variations, in any dimensions, of selected heads are to be expected and may be considerable, a method of correction is indispensable and the following has been adopted.

A standard head of approximately average dimensions is assumed and divided by imaginary sections, parallel to the zero planes, into cubic millimeters, each slice or lamella being 1 mm. thick and sub-

divided into square millimeters. By these divisions or ordinates the distance of any point from the zero planes can be readily ascertained.

Charts.—This theoretical standard is represented by charts, which are scale photographs of sections of the frozen cranium, in one or more planes, cut with a special saw, described in the first part of the atlas. Since it is very difficult to find heads of exactly standard dimensions, while the number of lamellæ and their subdivisions must be constant, the size of all subdivisions must vary proportionally to corresponding dimensions of the head. This is effected by proportional scales. As the heads selected for charts may be larger or smaller than the standard, the lamellæ may be more, or less, than 1 mm. thick and the square millimeters or coordinates, into which they are divided, may measure more or less than 1 mm. in either dimension. The head to be sawn is measured with the needle gauge (26) in the measuring cage (Pl. XXXIV), the result in millimeters is noted for each dimension and compared with the standard and the proportional scales are set accordingly. The scale now used with the saw for regulating the thickness of the lamellæ is a grating of parallel silk threads stretched between opposing sway bars. The threads are approximated by inclining the bars and can be set at intervals of 1 mm. or more, or less, by direct measurement, or by quadrant scales with which the grating is provided; the spaces between the threads being the coordinates which determine the thickness of the lamellæ cut by the saw. A reticulated screen is formed by two such gratings, one being superimposed upon the other, at right-angles to it; when the intervals in both gratings are equal, the meshes form squares, but as the gratings can be adjusted independently, the meshes may measure millimeters, or more, or less, in either dimension. The subdivisions of the lamellæ are regulated by this screen; in the standard they are square millimeters; in the selected head, the same number of divisions are made to measure millimeters, or more, or less, in either direction as the whole dimensions measure the same as the standard, or more, or less.

The **corrected screens** serve as scales of measurement which are photographed with the lamellæ, bringing them in both dimensions to the common measure of the standard head. This is the method of preparing standard photographs or charts.

Measurement of Heads.—The heads selected for operation must be measured and their dimensions compared with the standard in a similar way. If desired, millimeter scales may be used for directing

the needle, the necessary corrections for each movement in three dimensions being made by calculation or tables. It will be found in practice that when a number of observations are required, as in stimulation experiments, such constant interruptions as this involves are irksome and a mechanical method which effects the correction automatically is preferable. Two methods of this kind have been employed. For simple rectilinear movements a form of extensible scale (Pl. IX) is used which consists of a small steel spring enclosed in a tube with a longitudinal slot to expose the spring, the spirals of which serve as divisions of the scale. When the spring is slightly extended, the spirals are 1 mm. apart; they can be fixed at any point and made to measure millimeters, or more, or less. The rectilinear machine is provided with three of these scales to direct the excursion of the needle in three planes, and for this purpose they are regarded as ordinary millimeter scales; with a little care in setting them they are sufficiently accurate.

Adjustable Gratings.—The gratings of silk threads, already mentioned, are employed with the same machine, in a two-dimensioned indicator (Pl. XXVI) to direct the movements of the inclined needle, and three such screens are combined in a three-dimensioned indicator (Pl. XXVII) in the later modification. These gratings are the most satisfactory form of proportional scale; they are perfectly accurate and quickly adjusted. The three-dimensioned indicator is used to direct the movements of an operating instrument constructed on the principle of an equatorial, which gives the needle universal movement, an obvious advantage. Thus, by measurement from central zero planes with proportional scales, all heads, whether used for charts or operations, are reduced to the common measure of the standard head in all dimensions and the coordinates which form the units of measurement are equivalents of millimeters in the standard and are regarded as identical.

Having now given a summary of the principles on which the stereotaxic method is founded, a sketch of the use of charts, their preparation, corrections for size, measurement by proportional scales and the application of the same means to correct variations in the dimensions of heads selected for operation, I propose to complete this chapter with a brief review of the procedure adopted to direct and measure the movements of the needle in the two patterns of machine, including the two forms of indicator which have been mentioned.

Operating Mechanism. Direction and Measurement of Movements

A selected animal having been prepared and anæsthetized, the first step is to measure the head in three dimensions with a needle gauge, which gives the cranial measurements free from errors due to variations in the thickness of integuments, hair and muscles. With the rectilinear machine a needle gauge (Pl. XXIV) may be used with a rectangular cubical skeleton table, the cage (Pl. X, 64) attached to the head by the basal frame or head-vice (Pl. V). This is a quadrilateral, horizontal frame which surrounds the head at the level (22-23) of the basal plane and is fixed to it by two pairs of graduated screw clamps. By a pair of aural pivots (25) and orbital brackets (Pl. II, 9) secured by a face-piece or mask (Pl. II) and bit (8), the upper border of the frame is made to coincide with the center of the meatus and the lower border of the orbit on both sides, *i. e.,* the basal zero plane, and it is clamped in this position. At the same time, as the clamps and aural pivots are graduated and made to correspond on both sides, the head is centered, so that the median longitudinal plane of the frame coincides with the median sagittal plane of the head. The basal and sagittal zero planes of the frame and head therefore coincide and the frontal zero plane is also identical in both as it is drawn through the centers of the aural pivots and auditory meatus at right-angles to the line from the center of the meatus to the lowest point of the orbit, *i. e.,* the upper border of the basal frame. The basal frame or head-vice and the method of applying it are identical, whichever operating instrument is subsequently employed, and with both measurements are made with a needle gauge applied to a cage, but the latter is constructed in two forms. The cage (Pl. X, 64) is an essential part of the rectilinear instrument. The traversing stage (Pl. XIII) and needle carrier (71) are applied to its free surfaces and these also serve as bases for the needle gauge which is merely a form of depth gauge (Pl. XXII). But in the later machine, for operative purposes, the equatorial (Pl. XXX) takes the place of the cage, which is then required only for measurement with the needle gauge, and it is therefore advisable in this case to employ a cage constructed solely for gauging and drilling (Pl. XXXIV). The drill may not be wanted, but as the same guides serve for both gauging and drilling, the additional cost of it is trifling, and it is an advantage that it should be

available, if required. The objects for which it is necessary are explained in Chapter V. It is sufficient to mention here that with the rectilinear machine the ordinary cage is employed; the measurements in all available dimensions are taken with the needle gauge (Pl. XXII), and then the traversing stage (Pl. XIII) carrying the operating needle is applied to the same cage. If, however, the equatorial be used, a special measuring and drilling cage (Pl. XXXIV), which includes a needle gauge (26), is employed for measurement only, then removed and the equatorial substituted. Both forms of cage are furnished with four similar feet (Pl. X, 67-68) carrying bolts which fit into slots in the head-vice (Pl. V, 42-43) and are then locked.

Adjustment of Spring Scales.—In the rectilinear machine, after the selected cranium has been measured and the three adjustable spring scales (Pl. IX) have been set in accordance with its dimensions, their divisions will have the same proportion to millimeters as the whole dimensions of the selected head have to the standard, and the needle is directed by these coordinates instead of millimeters. The next step is the application to the cage (Pl. X, 64) of the traversing stage (Pl. X, 69) which carries the needle.

The Traversing Stage.— The needle carrier (Pl. XIII, 71) is mounted on a quadrilateral, rectangular frame (Pl. XIII, 69), like a microscope stage, with rack and pinion movements in both directions. The carrier (71) consists of a slide block travelling on the transverse guides of the stage (70 *a*, 70 *b*). Attached to this block, perpendicular to the stage, is a grooved plate, the outer sheath (Pl. XIII, 72), in which the inner sheath (Pl. XIV, 93) of the needle-holder slides. The outer sheath is attached to the slide block by a pivot and quadrant (Pls. X, XI, XII, 77) providing an inclination of 25° in one plane and direction, and the bed of the needle (Pl. XIV, 94) can be projected from the inner sheath by rack and pinion, completing the graduated movements of the operating needle in three planes.

The excursions are registered by millimeter scales to which extensible spring scales are fitted and both are read simultaneously by the same index. By means of steady pins and clamps the stage can be fixed to any of the free surfaces of the cage, above (Pl. X) where it can be made to face four different ways, to both sides (Pl. XI) and behind (Pl. XII), seven positions in all. When fixed in any of these positions the zero points of its scales coincide with the zero planes of

the head-vice and cranium and the engraved millimeter scales of the guides of the stage are graduated from both sides of these zero points.

Direction of Movements of Needle.—Whatever the position in which the stage is fixed, the index of the needle (Pl. XIV, 113) reads zero on its scale (Pl. XIV, 112) when the point of the needle reaches the zero plane of the cranium to which it is perpendicular, and however the needle is racked in or out, its index always shows the number of millimeters on the millimeter scale (112) and coordinates on the extensible spring scale (111) from the point of the needle to that zero plane. Similarly, the scales of the stage (Pl. XIII, 70-91) show the number of millimeters and coordinates between their zeros and the needle, and as these zeros coincide with the zero planes of the frame and head, we can recognize immediately how many millimeters and how many coordinates the needle is from the three zero planes of the cranium. The method of directing the needle to a given point in the brain by this mechanism can be made more intelligible by an example.

Localization of Objective Point.—Since any objective point in the brain must be found, in one lamella at least, in each plane, we may take our choice and locate it in the plane which appears most convenient in practice or, as in this case, merely to serve as an illustration. Let us assume that the needle is to be directed transversely from one side (Pl. XX), that the objective is a point in the thalamus, and that we decide to locate it in a sagittal lamella perpendicular to the needle, the number of the lamella corresponding to the number of millimeters or coordinates from the objective to the median sagittal plane. In the chart of the selected lamella we measure the distance of the objective from the lines representing the basal and frontal zero planes, using the corrected scales of the chart and regarding the units as millimeters in the standard. These are the data. We proceed to rack the needle the same number of coordinates on the extensible scales of the stage from the zeros coinciding with the basal and frontal zero planes by the two movements of the traversing stage which is parallel to the sagittal lamella and thus bring the needle exactly opposite the objective, pointing at it. The third movement, the projection of the needle in its sheaths, will bring it to the required point. To any one familiar with the instrument, it does not matter which plane is selected to locate the objective. If we located it in a frontal or horizontal lamella, parallel to the axis of the needle, we should bring

the latter to the edge of the lamella with one movement of the stage, and the other movement of the stage and the projection of the needle would bring the latter to any desired point in the lamella.

The Inclined Needle.—The outer sheath of the needle carrier (Pl. XIII, 72) is pivoted and swings on a graduated quadrant (77) which provides for an inclination of about 25°, within that limit it can be fixed at any angle in one direction and in one plane, but it can be applied to the top of the cage facing four different ways and therefore inclined in four directions, and by the movements of the stage it can be brought to any lamella in any plane, and thus the angular deflection is available, if required, in many positions. The inclination being only in one plane, the objective must be located in a lamella parallel to it and therefore perpendicular to the stage. By one movement of the stage we bring the needle to the edge of the lamella, set it at the required angle, and then, by two remaining movements, one of the stage and the other the extension of the needle in its sheaths, we can direct it to any point in the lamella. As an example, let us assume that we propose to direct the needle, from above, to a point in the right internal capsule, avoiding the caudate and lenticular nuclei. We locate the objective in a frontal lamella, fix the stage, above the cage; with the needle facing forwards (Pl. XIX) its plane of inclination will be parallel to the lamella and deflect the point of the needle to the left, the direction of the right internal capsule; the needle is set at the same angle as the capsule and fixed by the quadrant. We have employed one movement of the stage (longitudinal), measured by its proportional scale, to bring the needle to the edge of the lamella; there remain the transverse movement of the stage and the projection of the needle, and with these two movements it would be easy to direct the point of the needle to the objective if both were visible. This is not possible in the head, but we can reproduce the conditions in an instrument where we can see them, direct the needle to the required point by sight and by means of corresponding scales repeat the movement in the operating mechanism.

Two-Dimensioned Indicator, with Card.—Such an instrument is called an indicator. In the proposed example it need only be of two dimensions, for the needle has been brought to the plane of the lamella and we only want to ascertain the extent of the two remaining movements required to bring it, at a given angle, to the desired point. This can be effected by representing the lamella by a card ruled with square

millimeters and crossed by two lines corresponding to those marking the zero planes in the charts. If we remove the head and fix the card in the machine in exactly the same position as the lamella, so that their crossed zero lines coincide, the needle, fixed in any position, must have the same relations to those lines, and to any points at the same distance from them, in both card and lamella. We may therefore mark a square millimeter on the card, a given number of millimeters from the crossed lines, bring the point of the needle into contact with it, note the position of the needle by its scales, then retract it and replace the head in the machine and finally project the needle again to the position noted on the scale, to bring it to a point at the same distance from the two zero lines of the lamella in the brain as the square millimeter on the card is from its crossed lines. We can begin this proceeding by fixing the needle at a given angle on its quadrant scale and bring it to the marked square by two movements, one of the stage, the other its own projection, and by identical movements bring it to the objective point in the lamella, inclined at any required angle within the limits of its excursion. To save the trouble of removing the head from the machine and replacing it, the card may be fixed in a duplicate machine, the needle directed by sight to the marked square, and then by corresponding scales the movements can be repeated in the operating instrument and its needle brought to the objective point in the brain. It is not necessary that all the details of the operating machine should be reproduced in the duplicate if we secure the representation of those which are essential. The first step, when using the inclined needle in the operating machine, is to bring the needle to the edge of the selected lamella by one movement of the stage; this eliminates one dimension in the localization of the objective, the remaining movements, one of the stage, the other the projection of the needle, as well as its inclination, are in the plane of the lamella, so the duplicate instrument or indicator only requires two dimensions and the essentials of the operating mechanism are represented by a ruled card enclosed in a square frame, one side of which serves as a guide for a slide block on which an extensible needle or finder is pivoted with a quadrant and scale to fix it at any angle. The details correspond exactly with their counterparts in the operating machine; the size is the same or proportional throughout, and all scales are identical, so that movements in one instrument can be repeated in the other. As the card and the scales are graduated in millimeters, the measure-

ments are applicable only to heads of standard size; variations in the two dimensions represented of any selected head must be corrected by calculation, or by substituting for the ruled card an adjustable, reticulated screen formed by two superimposed gratings of silk threads at right-angles to one another (Pl. XXVI). The screen is adjusted to correspond with the two dimensions of the lamella of the selected head, the meshes are then coordinates representing the square millimeters of the card and the index point is determined, by counting them in the same way, from the central threads of the gratings which represent the crossed zero lines.

The Three-Dimensioned Indicator and Equatorial.—So far the description applies to the rectilinear machine with a single inclined movement of the needle and the method of directing it with a two-dimensioned indicator. It will be evident that considerable advantages may be secured by mounting the needle on an equatorial (Pls. XXIX-XXX), which affords universal movement, and directing it entirely by a three-dimensioned indicator (Pl. XXVII). These instruments are fully described in their place (Chapter VI), but with the help of the illustrations a short explanation will be sufficient to give the reader a general idea of the mechanism and its application, which is all I propose to attempt in this chapter. The equatorial is used as a substitute for the cage and stage of the rectilinear machine, the needle is carried in much the same way as the telescope in the astronomical instrument and has practically universal movement. The equatorial is supported on four feet terminating in bolts like those of the cage and they fit into the same slots in the head-vice; when applied to the indicator they fit into corresponding slots which have the same relations to screens representing the zero planes as the slots in the head-vice have to the zero planes of the cranium. Thus, the same equatorial can be adjusted in the indicator and the needle directed to the index point by sight, then transferred to the head-vice, and the needle will reach an objective with the same relations to zero planes of the cranium as the index has to the zero planes or index planes in the indicator. This method has the advantage of the greatest possible simplicity, for, though all the movements of the equatorial are recorded by scales, when it is used in this way, none of them need be employed except that which registers the projection of the needle. Obviously, the needle must be retracted while the skull is trephined and then

racked in till it reaches the figure noted on the scale, when it will be at the objective point. On the other hand, if duplicate instruments are employed, one applied to the indicator and the other to the head, a comparatively complicated operation can be carried out in the indicator and repeated step by step in the operating machine. In this case, every movement of both equatorials is regulated by the scales and precisely copied.

Three-Dimensioned Indicator with Ruled Card.—The simplest form of three-dimensioned indicator is a modification of that already described with a ruled card; it is provided with a horizontal table carrying a card ruled with square millimeters and crossed by two lines, representing the frontal and sagittal zero planes, like the chart of a horizontal lamella; the position of these lines being fixed in constant relation to four pillars with slots which correspond to those of the head-vice, so that the needle must have identical relations to the zero lines in both cases. The table carrying the card is supported on an extensible vertical pillar, graduated with a millimeter scale, by which the table can be raised or lowered with a rack and pinion. The upper surfaces of the slots of the four pillars represent the basal zero plane, as it does in the head-vice; and when the table is at this level the scale on the pillar is marked zero; the table can thus be raised or lowered any required number of millimeters above or below the basal plane. The index point is measured the same number of millimeters from the crossed zero lines on the ruled card as the objective point is from the corresponding lines on the chart of a horizontal lamella, and the square millimeter on the card is marked; the table is then racked to the correct height in relation to the basal plane and the marked square will be at the required distance from the three zero planes. The equatorial or cage can now be applied to the slots in the indicator and fixed, the operating needle directed from any position to the marked square on the card, the scale of the needle noted and the needle retracted sufficiently to be out of the way. Then, the equatorial, or cage, is transferred to the head-vice, the needle racked in till it touches the skull, this point is marked and the equatorial removed while the skull is trephined, then replaced and the needle racked through the brain till it reaches the objective point. As in the two-dimensioned indicator, this method with a ruled card has the disadvantage that there is no provision for correction for size and it is

necessary to make any that is required by calculation or tables. It is therefore more satisfactory to use the gratings in three dimensions.*

Three-Dimensioned Indicator with Adjustable Gratings.—(Pl. XXVII *et seq.*) Two horizontal gratings, one applied closely above the other and at right-angles to it, form a reticulated screen, the meshes of which can be made to measure millimeters, or more, or less, in both dimensions. To facilitate counting the threads they are divided into groups of five by contrast colors; white threads extend between the opposed pivots of the sway bars in each grating and represent the zero planes; other white threads are introduced to show the transverse and longitudinal dimensions in the standard cranium of the cat and monkey. One of the gratings is longitudinal, its central white thread represents the sagittal zero plane, and the intervals between the threads are the coordinates of transverse measurement. In the grating at right-angles to this the intervals are units of longitudinal measurement and the central white thread the frontal zero plane or interaural line. Vertical measurements are provided for by a single gridiron grating fixed vertically like a lawn-tennis net. A white thread between the pivots of its opposed sway-bars represents the basal zero and is level with the upper surface of the slots. All three gratings are set by direct measurement or quadrant scales, with which they are furnished, to correspond with the three dimensions of the selected head, or any segment of it.

An index point representing the objective point in the brain is adjusted in relation to the three gratings; it may be represented in several ways, the simplest of which is shown in Plate XXVIII. A vertical index needle (24), which can be raised or lowered in a slot at the end of a horizontal radius bar (23) by which it can be brought over any mesh in the reticulated horizontal screen, is fixed at any required distance from the sagittal and frontal zero planes and represents the index point in two dimensions. A horizontal index needle (29), carried in a vertical radius bar (27), is made to correspond with the space representing the required height above or below the basal plane in the vertical grating (16) and provides the measurement in

* The introduction of the card was suggested by Mr. Vellacott on grounds of economy. I have not employed it, as I think the correction of measurement by calculation, which it entails, is objectionable; the card is, however, much cheaper than the adjustable gratings and on this ground the method may be worth consideration.

the third dimension. If the points of the two index needles are made to meet, as shown in Plate XXVIII, either of them will serve to indicate the position of the index point, and the operating needle can be directed to it and, one index needle having been selected, the other may be removed. In practice it is rather inconvenient to bring the points of two needles precisely together like this; if the needles terminate in notches instead of points or one of them in a cross (Chap. IV, XXVIII, A), they can be adjusted more quickly. The operating needle of the equatorial or cage is directed to the index point, as explained in the description of the card indicator, and the subsequent steps of the operation are completed in the same way.

PLATES I TO XXI

Plate I.—Ear cones, guide, speculum, probe.

Plates II, III.—Mask.

Plates IV–VIII.—Horizontal frame or head-vice.

Plate IX.—Extensible scales.

Plate X.—The cage and needle, first position.

Plate XI.—The whole rectilinear machine with inclined needle, applied to cage in sixth position.

Plate XII.—Horizontal needle applied to rear face of cage, seventh position.

Plate XIII.—The traversing stage.

Plate XIV.—The needle-holder.

Plate XV.—Insulated platino-iridium needles.

Plates XVI, XVII.—Operating needles and beds.

Plates XVIII, XIX, XX, XXI.—Needle and stage applied to cat's head fixed in cage and head-vice. Needle in same position as in Plates X, XI, XII, in which the parts of the machine are numbered. The numbers are not repeated in Plates XVIII–XXI.

CHAPTER IV

ILLUSTRATED DESCRIPTION OF STEREOTAXIC INSTRUMENTS

Plate I

(IV) Ear cones for cat. (III) Ear speculum for cat. (I) Guide and (II) Probe for introducing cones.

(IV) These are hollow brass cones introduced into the auditory meatuses on both sides. The external orifices receive the tapered ends of the aural pivots (Pl. V, 25) which are fixed in the frame or head-vice (Pl. V). Their object is to support the head in the correct position in the frame till the screw clamps are adjusted and fixed. The cones center the meatus and, when fitted on the aural pivots, the interaural line, which passes from the center of one meatus to the other, is on a level with the upper surface of the head-vice which coincides with the basal horizontal zero plane of the cranium. Both cones and pivots are bored so that in the cadaver the interaural line can be drilled from one pivot to the other.

The meatus in the cat is not very accessible and, as the accuracy of the interaural line is the most important of all the data for adjustment and measurement, various forms of ear cones have been tried. The simple straight cone with only a slightly projecting disc is the best. It consists of the following parts: (1) The point or cone; (2) The disc; (3) The barrel. The point enters the meatus, the disc prevents it from going too far and the barrel receives the pivot. The introduction of the cones will be discussed under the head of operative procedure and will be referred to here only so far as may be necessary for the description of the instruments illustrated in Plate I, *i. e.*, the speculum and guide. The former does not require description. Its use is to expose the orifice of the meatus and when introduced for this purpose the pinna should be drawn directly outwards and illuminated with a good light. In the cat the orifice of the meatus is generally a mere slit and may be invaginated by the blunt point of the cone; it is sometimes advisable to use a guide to introduce the cones and a clamp should always be employed to hold them till the pivots are inserted. The guide is a small, flat, steel bar, 3 mm. wide, fixed

to a handle at an angle in order to keep the hand out of the line of slight; it is introduced for a few millimeters into the meatus and held there. A probe, at a similar angle with its handle, fits into the cone and projects 2 or 3 mm. beyond it, affording a finer point for entering the orifice of the meatus. There is a slot in the disc of the cone which fits the guide and slides readily along it if held in the right position, which is with the point of the probe in contact with the guide. The latter being held in the meatus with one hand, the probe with the cone on it is held in the other and the slot in the disc applied to the heel of the guide and then slipped along it, the point of the probe being kept in contact with the guide; if this is attended to, the cone slides easily into the meatus—if it is not kept to this line, it will jam. When the cone enters the meatus, it is pushed on as far as the disc will permit and the guide withdrawn simultaneously. The probe serves to hold the cone in the meatus till the clamp (Pl. III, 20) is applied, and is then removed. The same manœuver is repeated on the other side, and until the head is introduced into the frame both cones are kept in position by the clamp, which is then removed. It is convenient to have the guide in case it is required, but if the cone is mounted on the probe it can generally be introduced with little difficulty, and the guide is not necessary. There is not room at the apex of the funnel of the pinna for both speculum and cone at once, but the orifice of the meatus can be exposed with the speculum and, while it is withdrawn, if the pinna is drawn well out, the probe carrying the cone can be directed to the opening.

Plate II.—The Mask

The posterior border of the basal horizontal zero plane, represented by the interaural line, having been brought to the level of the upper surface of the horizontal frame or head-vice, the front part, represented by the lower borders of the orbits, is similarly adjusted. This is effected by a face-piece or mask in which two recurved brackets (9) hook over the lower margins of the orbits and are retained in that position by a bit (8) which passes into the mouth behind the upper canine teeth. The bit is a flat brass bar, perforated near both ends with slots which are long enough to allow for differences in the distance between the eyes, and through these slots screws (16) descend from the brackets; split nuts (11) can be rapidly applied to the

screws below the bit and one or two turns are sufficient to fix the brackets against the counter pressure, acting through the bit, on the teeth of the upper jaw. In fact, the brackets and the bit grip the upper jaw between them like the blades of a pair of forceps. Projecting horizontally outwards from the sides of the mask are two arms (14) which are brought into contact with the lower border of the horizontal frame when this is lowered over the head. When they are in this position, the under surfaces of the brackets and therefore the lower margins of the orbits, which are in contact with them, are level with the upper border of the head-vice and the whole of the basal horizontal plane of the head exactly coincides with the upper surface of the horizontal frame of the instrument. The horizontal arms are secured in position by two clamps (Pl. VI, 46, 46). The distance between the orbital brackets can be adjusted to that between the eyes by a sliding joint and screw (17 and 18).

Plate III.—Cat's Head with Mask, Side View

View, from the side, of a cat's head with the mask and ear plugs in position ready for adjustment in the frame of the stereotaxic instrument. The ear plugs are held in position by a clasp (20) which is removed after the head is adjusted.

Plate IV

A front view of Plate III.

Plate V.—Horizontal Frame or Head-Vice

This is a rectangular brass frame consisting of a frontal, an occipital and two lateral bars, connected by joints and large enough to admit the head of a large cat or rhesus monkey.

The upper surface of the frame represents the basal zero plane of the cranium and is adjusted and fixed so that it exactly coincides with it. The adjustment is provided for: (1) By the aural pivots (25), the inner extremities of which are tapered to fit the ear cones and their centers, corresponding to the interaural line, are level with the upper border of the horizontal frame; (2) by the mask (Pl. II) which brings the lower borders of the orbits to the same level; and (3) the head is centered sagittally and secured by four graduated screw clamps (27, 30). The pivots slide in joints (36) fixed at corresponding points

on the lateral bars (22) of the frame; the latter are graduated throughout their length in millimeters which are read forwards and backwards from the interaural line; this is their zero point and all movable joints which slide on the lateral bars are secured by screws at corresponding points on both sides. The four clamps (27-30) for fixing the head terminate internally in "grips" (29, 32), small plates provided with three steel points to pierce the skin and hold against the bone without penetrating it, and the two pairs are somewhat differently arranged. In the anterior or temporal pair (29), the plates are triangular, with one point above and two below, engaging the zygoma which lies between them. The posterior or mastoid pair (32) are applied to that prominence immediately behind the meatus. The adjustment of the cranium with these clamps and the selection of the best pattern for the purpose have been a source of some trouble. They were unsatisfactory in the old instrument, where, after trying a variety of grips, I adopted, for each of the four clamps, a single rather obtuse-angled steel point rotating at the end of a screw which perforated a sliding joint on the lateral bar, fixed where it was required. The form of both grip and clamp is defective. A single screw passing through the sliding joint is not rigid enough, it is very slow and under pressure the points do not rotate readily and are apt to twist up the skin and sometimes to deflect the head. The occipital region of the cranium in many animals, and notably in the cat, is in the form of a wedge in two planes; that is to say, in the horizontal plane the apex of the wedge is directed backwards, in the frontal plane downwards. With single blunt points and the force applied entirely by screws, there is a tendency to lift the head with the bilateral pressure, and if sharper points are used to obviate this, they may penetrate the bone to a variable depth. These defects have been removed. The plate, carrying three points which form the mastoid grip, is inclined in two planes like the mastoid itself, so that all three points engage it.

Adjustment.—Instead of being carried by a single screw, there are two bars which perforate each sliding joint (35, 37); one above and one below the horizontal frame. Internally, *i. e.*, medially, the two bars are attached to the grip (29, 32); externally, their extremities are united by a short plate. The center of this cross-plate is perforated and gives passage to a triple-thread screw which is fixed by its inner extremity to the sliding joint on the lateral bar. This screw, therefore, is parallel to the sliding bars which carry the grip and lies

between them. A nut (28, 31) is fitted to the outer end of the screw and works up to the cross-plate. The sliding bars, with the grip at one end and the cross-plate at the other, form a rectangular frame which slides to and from the median plane, towards which it is driven by the screw-nut. It is pushed in till the grip is in contact with the skull, the nut is run up rapidly on the screw till it reaches the cross-plate and then effects the final adjustment and fixture of the head. All the four clamps are made in this way, millimeter scales are engraved on the surfaces of the upper sliding bars, as well as on the aural pivots, and are arranged so that all six scales can be easily read from the same point in front and rapidly compared, which ensures accuracy and saves time.

The clamp (20) for holding the ear cones in position assists in adjusting the head on the aural pivots. When the frame is lowered over the head, the latter is raised till the ear cones are opposite the pivots, which are then pushed home, the horizontal arms of the mask being brought almost into position below the horizontal frame by the adjustment of the pivots and cones; all that remains is to hold the arms in contact with the lower border of the frame, slip the clamps (46) over them, noting that they are equidistant from the pivots on both sides and fix them. The occipital bar (24) is brought into contact with the occiput and its sliding joints (38) and those of the four clamps (35, 37), are fixed by the screws at corresponding points on the lateral bars (22). The opposed clamps are then adjusted in pairs, the grips are pushed up, the nuts run up the triple-thread screws and one or two turns will suffice to hold the head firmly, with identical readings of the scales on both sides; the aural pivots are made to correspond and carefully inspected to see that they and the cones are well home. From the accessibility of the head in the frame its position can be thoroughly inspected after it is fixed and any error ought to be detected and corrected before the cage and travelling stage are applied.

Plates V, VI represent the basal horizontal frame or head-vice as seen from above.

V. The frame from above.

VI. The frame with the mask and ear plugs in the position they occupy in the frame, but without the head.

VII. The same as VI, but with a cat's head in position.

VIII. The same head in position viewed from the side.

Procedure.—The next steps in the procedure are the application of the cage, measurement of the head, comparing its dimensions with those of the standard, setting the extensible scales accordingly and fitting them in their places. The traversing stage, with the pilot needle, is applied to one of the surfaces of the cage and fixed with clamps. The pilot needle is brought into the correct position in contact with the cranium, which is marked with the drill, then trephined and the pilot racked down to the selected point. The electrolytic or other form of operating needle is then substituted and the operation completed. It will be convenient to describe the extensible scales next, as they appear in the illustrations of the cage, and their application follows immediately in the order of operative procedure.

Plate IX.—Extensible Scales

Each scale consists of a fine spring enclosed in a tube open down one side to expose the spirals which can be made to measure millimeters, or more, or less. The spring is fixed to the tube at one end and at the other to a screw rod (57) which passes through the neck (58) into which the tube is drawn and through three milled heads (Pl. IX 59, 60, 61). The proximal one (59) moves the spring as a whole so that, after it has been set, any particular spiral can be brought opposite the zero of the millimeter scale without moving the tube or altering the extension of the spring. The middle milled head (60), which fits over the elongated neck (58) of the tube, tightens or relaxes the grip of the latter on the screw rod which passes through it. The rod can be drawn in and out and the spring extended or contracted and fixed anywhere by screwing the head up. It is convenient, while the spring is being set, to fix this head sufficiently to make the spring retain any position given to it, but not to prevent its adjustment. The third (distal) milled head (61) fits the screw rod and serves as a fine adjustment for the spring, but of course can act only when the middle head is relaxed. To facilitate reading, the spirals are painted black and white in alternate groups of five and an ivory millimeter scale, also marked in groups of five, is attached to each scale by spring clips. These ivory scales are not absolutely necessary, but are added to facilitate reading and the division into groups of five is a great assistance for this purpose; they are adjusted to correspond with the permanent scales on the instrument and the

extensible scale is between them. The zeros of all these scales are made to coincide and the index reads their divisions simultaneously.

All measurements are from zero and the operator requires to know how far the point of the needle is from each of the three zero planes. On this triple scale he sees at once how far the needle is from the zero plane from which it is counted in millimeters, by the engraved scale on the instrument and the ivory scale which is identical with it, and at the same time how far in coordinates, or corrected divisions, shown by the spirals of the spring.

In practice, the extensible scale is set, so that the divisions of the spiral spring bear the same relation to millimeters as the dimensions of the cranium of the experimental animal do to the standard. The number of divisions is always the same as the number of millimeters in that dimension of the standard, but they may measure millimeters, or more, or less, just as the whole dimension may be the same, or more, or less.

Gauge for Setting Scales.—For setting the scale, it is convenient to have a gauge with a millimeter scale and two clamps which hold the tube parallel to it. Between the scales are two sliding double indices which point both ways, one point reading the millimeter scale, the other, the spirals of the extensible scale; their use will be best explained by an example. The transverse dimension from the zero plane to the surface of the standard head in the cat is 21 mm.; hence, this diameter must always be divided into 21 units, whether millimeters, or more, or less. Suppose the same diameter of the experimental cranium is 19 mm. the indices are set 19 mm. apart on the millimeter scale; the spiral spring is then adjusted till 21 spirals are included by the opposite points of the same indices; *i. e.,* the 21 spirals measure 19 mm. If, on the other hand, the diameter had been 24 mm. the 21 spirals would have been made to measure 24 mm.*

There are one or two practical points to be observed in setting these scales. A spring fixed at one end expands rather more, when it is extended, at the free end than at the other, and if it is simply extended to the required length, there may be an appreciable difference in the divisions at the two ends. This can be corrected by extending the spring till the intervals near the fixed end are slightly greater than their final measurement and then letting the whole spring gradually

* An illustration of this gauge has been published in the Atlas, Part I.

contract till they are correct. The edge of the slit in the tube is graduated in 5 mm. divisions and, if the spring is set to measure millimeters, it can be seen whether the spirals are uniform and, with a little practice, they can be set correctly without difficulty. The scale should always be set, in this way, to measure millimeters before it is finally adjusted to a proportional scale; the alteration required is usually slight and the possible error minute, but even then it is better to overextend the spring slightly and let it drop back. After all, it is not the defect of a fraction of a millimeter that matters, but the cumulative error which occurs without an extensible scale and may sum up to several millimeters.

When fixed in the instrument the spiral selected for zero must be made to coincide with the zeros of the millimeter scales and the index reads them simultaneously. This adjustment is effected by the first milled head, as previously explained. As the travelling stage is applied to the top of the cage in four different positions, the operator must make sure that the scales are applied to the diameters of the head for which they were set.

Plates X, XI and XII.—Cage and Traversing Stage

The above plates give a general view of the instrument with the needle applied in three different positions.

X. Shows the cage with the traversing stage (69) applied above it, secured by clamps (90) and the needle in its holder in the vertical position. This is the first position, the needle-holder facing forwards. In the second position, the traversing stage is exactly reversed and the needle faces backwards. All the three extensible scales with the ivory ones attached are in position. There are two movements of the traversing stage and a third of the needle-bed in its sheaths. The quadrant (77) enables the needle-holder to be set at various angles, the inclination in the first position being downwards and to the left (of the head), *vide* Plate XIX.

XI. Shows the traversing stage and needle applied to the left side of the cage, sixth position. It is shown inclined downwards and inwards; *i. e.*, towards the middle line.

XII. Here the traversing stage and needle are applied to the back of the cage, seventh position, the needle is horizontal, but can be inclined downwards and forwards.

The cage is sufficiently illustrated in the above plates; it requires very little description itself, as it is merely a skeleton table to support the traversing stage which can be fixed to four of its surfaces. It is fastened to the frame by four feet (67, 68); these carry round bolts which drop into the slots (42, 43) in the frame and the feet are locked by screws (44, 45) half cut away to avoid the necessity of removing them and the risk of their being mislaid. So far, the object of the cage is very simple, but its dimensions are important, as they are necessary factors in the measurement of the head and the excursion of the needle. In planning the dimensions of the first instrument of this pattern, realizing the great importance of rigid support, for accurate movement of the needle, and wishing at the same time to keep the machine light, it was desirable, in all positions, to fix the needle as near the héad as possible, and the three diameters of the cage were made approximately proportional to those of the cranium. Consequently, the distance from the surface of the cage to the zero plane parallel to it was different, in the vertical, transverse and longitudinal diameters. This involved an element of complication in measurement, for scales and instruments had to be adjusted separately for each dimension. As the whole instrument is now always suspended on springs and supports the head, a slight increase of weight is immaterial. The dimensions of the present cage, from the surface to the parallel zero plane, are identical in all three diameters and no adjustment of scales or instruments for measurement from different positions is required. This simplifies the procedure and the cage has been strengthened sufficiently to allow of the alteration without risk of impaired accuracy.

As soon as the cage is secured, the measurements of the cranium are taken in its vertical, transverse and longitudinal diameters, with the needle gauge (Pl. XXII), described in Chapter V. The measurement of the anterior longitudinal diameter in the cat is discussed in the same chapter.

The measurements of the cranium are compared with those of the standard, the extensible scales (Pl. IX) set accordingly and inserted in the clamps (84, 86) provided for them in the traversing stage (69) and inner sheath (93) of the needle-holder and their zero points made to coincide with those of the millimeter scales.

Plate XIII

The **traversing stage** is a square frame for carrying the needle and its holder with a graduated movement in three planes, two in the plane of the stage and one perpendicular to it. With clamps and steady pins, the frame can be applied to the free surfaces of the cage in seven positions, four above, that is, facing four different ways, forwards, backwards and to either side, and it can also be fixed to both sides and the back of the cage. It is always fitted so that crossed lines, passing through the zero points of its longitudinal and transverse scales, coincide with the crossed zero lines of a lamella, parallel to it, of the cranium or charts. As it is applied in several positions, the relations of its parts and their movements are subject to similar variations; but for purposes of description, and always unless otherwise stated, it is assumed to be in the first position on the top of the cage (Pl. X), the needle facing forwards, its carrier moving on transverse guides (70*a*, 70*b*), these in turn travelling on longitudinal guides (91) and the terms right and left corresponding to the sides of the head in the machine. So, the movements, like those of the stage of a microscope and effected by rack and pinion, are longitudinal and transverse in the first position, but are reversed when the needle faces left or right; and when the stage is applied to the right, left, or rear faces of the cage, the transverse movement becomes vertical and, in the latter case, the longitudinal becomes transverse. The needle is fixed on a bed (94) perpendicular to the stage, this is moved by rack and pinion in an inner sheath (93), which slides in an outer sheath (72), the latter being pivoted to the needle carrier (71), and with a quadrant scale (77) it can be inclined, at any angle up to 25°, in one direction and in one plane; but since it can be brought to any plane by the movements and positions of the stage, a large choice of positions, inclination and movements is provided.

The changes of direction on the top of the cage are introduced only for the purpose of varying the angle of inclination; for a vertical needle, one position is sufficient. In the first four positions referred to it can be inclined downwards and to the left, downwards and to the right, downwards and forwards and downwards and backwards, respectively.

In every position the crossed lines, real or assumed, are the identical zeros in stage, chart and the lamella of the head itself, and measure-

ments are reckoned from both sides of them in millimeters or coordinates. In the stage, millimeter scales graduated from these zero points are engraved on the transverse (70*a*, *b*) and longitudinal (91) guides; attached to them are extensible spring scales (82, 83) which are adjusted proportionally to the dimension they represent, after gauging the selected head; the spirals representing coordinates, which bear the same ratio to millimeters as the whole dimension does to the standard. Ivory millimeter scales (88, 89) are also attached to the guides. Thus, there are three sets of scales for each movement, the engraved scale on the guide, an ivory one and the extensible scale between them. They must always be adjusted so that their zero points coincide and the same index reads them all simultaneously, keeping the observer informed of the number of millimeters and coordinates between the needle and the zero plane to which the scales relate. Ivory scales are not absolutely necessary and can be dispensed with; they were introduced because brass is so easily tarnished and stained in operations that it is sometimes difficult to read the scales on the guides. In future I propose to employ white metal not so easily affected which will I think make the ivory scale superfluous.

Direction of Needle.—The carrier (71), with the needle in it, is racked with transverse and longitudinal movements from either side of the crossed zero lines of the stage and any parallel lamella of the cranium and it is easy to bring the needle opposite to any selected point in the latter by these movements. The selected point must lie in at least one lamella in each plane; if we locate it in one parallel with the stage, we can imagine the chart of this lamella used like a lantern slide and inserted in the place of the actual lamella in the cranium, its ruled zero lines coinciding with crossed lines drawn between the zero points of the stage. We identify the objective point by measurement from the two zero lines of the chart lamella and move the carrier the same distance from the corresponding zeros of the stage. The needle must then be opposite the objective and it only remains to rack or slide it up to that point. The measurement of the projection of the needle will be described in another section. In the example given, where the objective is located in a lamella perpendicular to the needle, the function of the stage is to bring the needle opposite the objective point by two movements, leaving the third, the projection of the needle, to bring it to the required point; but the objective may be located, if preferred, in a lamella perpendicular to the stage

and parallel to the needle. In that case one movement of the stage brings the needle to the edge of the lamella, the second brings it into line with the objective, which is reached by the projection of the needle; as, for example, one movement might bring a needle in the same plane to the edge of a certain page in a book, a second movement to a particular line on that page, and the projection direct it to a particular letter. This method is adopted with the inclined needle, and will receive more detailed explanation elsewhere (Chapter V); but it may be mentioned here that, as the needle can be inclined only in one plane, the objective point must be located in a plane parallel to that inclination and therefore perpendicular to the stage. The needle is brought to the edge of the selected lamella by one movement of the stage, as if the lamella were the page of the suggested book; by the second movement of the stage and the projection of the needle, it would be easy to bring the point of the latter to any letter on the page if they were visible. Thus, of course, they are not in the cranium, but it is practicable in the indicator described in Chapter VI, where all the parts are represented and in view, and the movement can be copied and repeated in the operating machine. It should be noted that one movement of the stage measured by its corrected scale brings the needle to the edge of the lamella; the other two movements are determined in the indicator, and are merely copied in the machine by corresponding scales in which millimeters, not coordinates, are employed, any corrections required having already been made in the indicator.

A mechanical detail connected with the stage must be mentioned. Both transverse guides (70*a*, *b*) have millimeter scales engraved on them. In one, the posterior (70*b*), the zero is at the center, *i. e.*, halfway up the guide, and the scale is graduated from it on both sides. On the anterior guide (70*a*) the zero is at the end, the scale is graduated towards the center and the syllable *Trans.* is also engraved, indicating that this scale is used when the needle is directed transversely, as it is when the stage is applied to either side of the cage (positions 5 and 6). The scale on the posterior guide, which is employed in all other positions, is not available when the stage is applied to either side (5 and 6). In the first four positions, where the stage is above the cage, the zero of the posterior guide, which is in the middle, coincides with either the frontal or sagittal zero plane of the instrument and head. When the stage is applied to the rear face of the cage and

the transverse guides are vertical, again this median zero is level with the upper border of the horizontal frame and the basal zero plane. But the stage cannot be applied to the sides of the cage at this level (positions 5 and 6), owing to the clamps and screws of the lateral bars, and it must be applied with the edge of the stage resting on the horizontal frame (see Pl. XI). This is the vertical zero, and obviously cannot be measured by the scale of the posterior guide, as its zero point cannot be brought down to this level; hence, the scale of the anterior guide is used for these two positions 5 and 6, and is read upwards from a zero level with the upper surface of the horizontal frame or head-vice.

Seven Positions.—The beginner may experience some little difficulty in recognizing the seven positions in which the stage is applied. The illustrations will assist him and, in addition, the following points. The four positions on the top of the cage are identified by the aspect of the needle which may face forwards, backwards, or to right or left. In the three remaining positions the transverse guides are vertical and the needle horizontal. Held in that position, the projecting quadrant scale (77) may be above the needle, or below it; it should be above in all the positions, so that the point of the needle can be inclined downwards. If the stage is held with the transverse guides vertical and the quadrant above the needle, it can be applied in that position to the right, left, or rear face of the cage, resting with its edge on the horizontal frame in the lateral positions 5 and 6; but in the seventh position, behind, the central zero of the posterior guide must be level with the upper surface of the frame. When applied as directed, the steady pins will fit into the holes belonging to them, and the stage must be secured with its two clamps.

Plate XIV.—The Needle-Holder

In describing the **needle-holder** it is assumed to be in the first position (Pl. X), standing vertically on its point, the face of the ivory bed (94) looking forwards, the locking screw (96) at the top and the extensible scale (111) on its right.

Its object is to carry various needles, with their special adjustments and, in the case of the electrolytic needles, with electrical connections, in a plane perpendicular to that of the travelling stage and to one of the three zero planes of the instrument and the cranium. On the

right side, the scale (112) for recording rectilinear movements is attached and set, so that the distance of the point of the needle from the zero plane to which it is perpendicular is always shown, and when the index reaches zero the point of the needle is at the zero plane. On the left, the indicator scale (110) for inclined movements records the length of needle projected from pivot to point.

The **needle-holder** consists essentially of a bed (94) and two sheaths, an inner (Pl. XIV, 93) and an outer (Pl XIII, 72). The bed, which is made of ivory for the electrolytic needle and of brass for the others, has the needle and its special appliances attached to it and travels in the inner sheath by a rack and pinion movement, which may be regarded as a fine adjustment; on the right (rectilinear), its excursion is registered by an adjustable index (113) attached to the bed and by extensible (111) and ivory millimeter scales (112), fixed close together on the inner sheath. The index reads both at once and they have the same zero, which always corresponds to the zero plane to which the needle is perpendicular, *i. e.*, when the point of the needle is at that zero plane, the index is at zero on the scales, so that the index always records the distance of the point of the needle from the plane in millimeters and in divisions of the spiral scale at the same time. These are called scales of the rectilinear needle. The inner sheath slides in the outer, which is pivoted to the carrier of the travelling stage (Pl. XIII, 71). It is provided with a graduated quadrant and clamp by which the needle can be directed and fixed at various angles. With inclined movements we employ the indicator scale on the left, which records the length of needle projected in millimeters only. The sliding movement between the inner and outer sheaths serves as a coarse adjustment for the excursion of the needle and can be arrested and locked at any point by the milled head (96) above the holder.

The inner sheath, which is made of brass, terminates at its lower extremity in two jaws together forming a blunt point called the stop (97). The jaws, which spring apart sufficiently to admit the needle, are brought together by a tension screw (99); they are lined with ivory, and grooved in the center for the needle, which is thus supported close to the cranium. The sliding movement of the inner sheath, which includes the stop, also carries the bed and the needle with it, while the rack and pinion project the needle through the stop.

These arrangements and movements, the sliding between the sheaths, the racked projection of the bed, the quadrant regulating the inclina-

tion of the outer sheath and therefore of the needle and the scales by which the movements are regulated, which will be described immediately, are applicable to all varieties of needles, but two or three different forms of bed are adapted to the particular objects of the needles attached to them. The beds all fit the inner sheath and can be easily interchanged, a necessary provision, as no matter what needle is employed it is always preceded by the pilot needle (Pl. XVI, 1), a plain steel needle tapering to about the same caliber as the one which follows; it penetrates membranes, is not easily deflected and traverses structures with little injury. As soon as it has reached the required point, it is retracted, the bed to which it is fixed removed and an operating needle, already mounted on its bed, substituted. The pilot needle requires no manipulation beyond its linear projection and is always kept mounted on a plain brass bed engraved with scales, but with no other fittings. With all forms of steel cutting needles, cyclotomes, spherotomes, etc., requiring some manipulation for projection and withdrawal of the concealed knife, rotation, etc., a special bed (Pl. XVI, II) is necessary; it is suitable for any of these needles and they can be quickly attached and removed.

The platino-iridium needles sheathed in glass which are used for electrolysis and stimulation are mounted on an ivory bed with electrical connections.

A general account of various needles was given in Chapter I, p. 17, as their application and use form the essential object of the stereotaxic method and instruments, but it is advisable to add a detailed description of the needles and the beds on which they are mounted in this chapter.

Beds for Pilot, Cutting and Insulated Needles.—Three different forms of bed are used and represented in the plates. They all fit the inner sheath (93) of the holder, and when racked down by the milled head (95) the needle which is attached to them is projected through the stop. Those for the pilot and cutting needles are made of brass, but the bed for the insulated needles used for electrolysis or stimulation is made of ivory and fitted with adjustment for the glass sheath and wires and electrical connections.

Bed for Insulated Needles.—This bed is shown in the illustration fitted in the inner sheath (93) of the holder, forming part of an arrangement for fixing special needles and also for directing and measuring their movements and fulfilling their special requirements.

The coarse or fine projection movements of the needle have been referred to and their measurement will be fully described (Chapter V). They are required for all forms of needle and are secured by the sliding and racked movements of the inner and outer sheaths and the bed and the inclination of the carrier which are available with all varieties of bed, and these parts are indicated in the illustrations by the same numbers. But the special requirements of different forms of needle cannot be provided by a single bed and the varieties alluded to will now be described. Special means are required for fixing the glass and platino-iridium needles, for the connections of the wires for the passage and insulation of electrical currents for electrolysis and stimulation and the rapid adjustment of the wires for these purposes. The provisions which this bed has to meet may be enumerated as follows:

1. For fitting the glass needle quickly and accurately and replacing it if it should break.
2. For connecting the wires of the needle with the leads from the battery or switch.
3. For bringing the stop into circuit when required, "live stop."
4. For adjusting the length of the wires and their projection from the point of the glass needle.
5. Against short-circuiting by water.

These requirements are met by the following arrangements:

The bed (94) is made of ivory and has an adjustable index (113) for reading the rectilinear scale on the right, and on the left is the scale for the inclined needle (110).

Clamps.—It is important that all clamps which hold the needle should open from the front (or from above, if the holder is lying on its back) so that the needle can be laid on its bed at full length. It is inconvenient to pass rigid and fragile glass needles through holes or under clamps. It is so much easier to make clamps with screws which pin the needle to the bed that it has been difficult to abolish them, but in the present holder lateral clamps are employed. The jaws of the stop (97) are first separated; next a pair of jaws (102, 102) are opened by two eccentric cams (103, 103). Each of the milled heads of the cams has a line marked on its anterior surface, and when the two lines are at corresponding angles, the jaws are equidistant from the middle line; in other words, they center the needle. A small piece of fine rubber is drawn over the needle between

these jaws and secures a firm hold without the risk of fracture. At 104-105 there is an arrangement to prevent short-circuiting. The wires leave the double glass tubes almost touching one another and may be short-circuited by a drop of water. It is not necessary to sluice the needle with hot water and the free douche is bad for animals and instruments, but if it is resorted to, a provision of this kind is indispensable. The accident is prevented by the ivory wedge (105) tapering to a knife-edge which passes between the wires till it is in contact with the glass. Before the needle is placed in position, the arm (104), which is fixed on a pivot, is swung out of the way. A small piece of thin rubber, with a notch in it to receive the edge of the ivory wedge, is first laid on the ivory bed, the needle on this, and a second piece of rubber, like the first, is laid over the needle. Then the arm (104) is swung back to its place; it carries, on a screw, a small plate with a notch like the pieces of rubber and which also like them receives the edge of the ivory wedge; then the whole is secured by two or three turns of the screw. The end of the glass needle and its two wires are sandwiched between the bed and plate and the two pieces of rubber; the latter project a little way on both sides of the wedge and being in firm contact no water can pass between them.

The wires, which can be seen on both sides of the wedge, drop into slits and are gripped by clamping screws in brass sliding shoes (107, 107); the *terminals* (108, 108) which receive the leads from the switch are fixed to the same shoes, establishing a connection between the leads (116, 117) and the wires of the needle. The shoes are attached to screws (109, 109) and by means of two small drums with milled heads, which can be worked easily with the tip of one finger, the shoes, and therefore the needle wires, can be projected and withdrawn and the wires at the needle-point adjusted with great nicety.

The millimeter scale (110) on the left of the bed, which is used when the needle is inclined, is read by an adjustable index seen in Plate X, 79. This and the extensible (111) and ivory millimeter (112) scales of the rectilinear needle, which have been mentioned, will be more fully explained immediately. Three leads are seen (116, 117, 118). At one end they are connected with the switch (Pl. XII, 140); at the other, two of them with the shoes and so with the wires of the needle, and the third with a terminal (101) which can be connected by a shunt (100) with the metal jaws of the stop. The shunt is not absolutely necessary, since the leads can be disconnected

at the switch, but it is an additional precaution. It is useful to be able to bring the stop into circuit when faradic currents are applied for the stimulation of deep centers or tracts. When these are excited with an insulated needle, it is often difficult to decide whether the response is genuine, *i. e.,* originates at the point directly stimulated and can be regarded as evidence, so far, of a function of that structure, or whether it is really elicited from some more excitable area near enough to be affected by what is called escape. It is not always possible to settle that question. In some cases, by numerous experiments in different animals with currents of various strength and by comparing the results with those obtained by direct stimulation of the suspected areas, a fairly definite conclusion can be reached. Considerable assistance may be afforded by having at hand a means of quickly changing the circuit so that different structures are implicated. As a rule, the shorter the arc the better; there is less chance of other structures being involved, so it is generally advisable to use the double-barrelled or the concentric needle with an arc of little more than 1 mm. between the points. If the stop is employed, it must be in contact with the surface of the brain, then, by a single movement of the switch, one of the needles can be disconnected and the live stop brought into circuit by the lead at 118. The current then passes through the brain between the stop and the point of the focal needle. Another movement of the switch disconnects the live stop, brings the whole instrument into circuit and the current passes between the focal needle and all the points of contact of the instrument with the surface of the cranium. Without any loss of time, therefore, these three variations of the circuit can be tried immediately one after the other, the results compared and useful information may be obtained. It is obvious that, if there is escape, it is more likely to occur under the latter conditions, with an extended and diffused arc; hence, if the response is more marked under these conditions the probability of the first result having been due to escape is increased. There may also be some difference in the character of the response and it is an advantage to have these alternatives provided for.

Pivot Stop Line.—On the back of the inner sheath of the holder there is a transverse line on which the letters *P. S.* are engraved; they stand for the words "pivot stop" and indicate that when this transverse line coincides with the top of the external sheath, the point of the stop is level with the center of the pivot. The needle is inclined

by rotation on this pivot, which is the zero from which its length is measured; this must be known to make the operating needle correspond with the finder of the indicator.

Plate XV.—Insulated Platino-Iridium Needle

Platino-iridium needles insulated in glass tubes are employed for electrolysis and stimulation; one of the double-barrelled variety is shown, mounted, in the illustration of the needle-holder.

I have not made any alteration in the three varieties of these needles which I designed, and of which a description has been published (1). They comprise the single needle (1), the double-barrelled needle (2) and the concentric needle (3).

For electrolysis the single needle is nearly always used. It is easily introduced and makes a smaller wound than the others. Any size may be selected and the exact amount of wire protruding precisely regulated by the attachment of the sliding shoe (107). With these variations and regulation of the intensity and duration of current, the exact size of the lesion required can be accurately controlled with a little practice. The anode should always be employed if precise circumscribed lesions are desired. With a wire of 0.3 mm. diameter, projecting 1.5 mm., and 5 ma. current, for 20 seconds, a spherical lesion of about 2 mm. in diameter can be obtained.

The head-vice, with its numerous points of contact, serves for the indifferent electrode, or a pad saturated with saline solution may be applied to any part of the skin.

If it is desired to make an electrolytic lesion in a structure from which some response to excitation can generally be elicited, it is usual, after introducing the needle, preferably the single one, to try the effect of a preliminary stimulation to verify the position. In this case, and, as a rule, when the single needle is employed for stimulation, it should be used with the live stop, which must be in contact with the surface of the brain; but must of course be disconnected for the electrolysis, or it would produce a cathodal lesion of the cortex.

But for excitation generally, the *short arc* affords the best chance of avoiding escape and one of the double needles should be employed, corrected by varying the circuit in the way already described.

The glass sheath of the double needle is made by fusing two small tubes together for a short distance and then heating and drawing them

out. For the double-barrelled needle (2) they are brought to a point on a fine carborundum wheel and the ends of the wires ground parallel with the orifice. In the concentric needle (3) one wire is pointed and projects from the end of one of the tubes, as in the single needle; the other glass tube is ground away two or three millimeters below its fellow and the wire from the second tube is flattened and fused into a little collar, about 1 mm. broad, which encircles the first tube about 1 mm. from its extremity, the point of the first wire being separated from the collar by about 1 mm. of glass tube, the current passing between the point and the collar. In all the needles, by the attachment of the wires to the shoes on the needle-holder, the exact adjustment of the termination of the wires, their relation to one another and to the ends of the glass tube can be easily regulated. The double-barrelled needle traverses tissues more readily and makes a smaller track than the concentric, but the latter gives a more equably diffused current, which is advantageous for the stimulation of groups of cells. When the operator desires to mark the point at which a particular response was elicited, either of the needles can be employed for the purpose. The apparatus should be kept arranged so that a galvanic current from a battery with a milliamperemeter and rheostat, and also a faradic current from an induction coil, can be switched on or off and interchanged at pleasure; by the switch on the instrument it can be directed into one or both of the wires of the needle and the size of the lesion determined. If both wires of the concentric needle are brought into circuit, a lesion of considerable size is quickly formed.

The following table gives some idea of the sizes of the needles and glass tubes commonly used:

	Standard wire gauge (British)	Diameter in mm.
1. Single needle, fine	32	0.19
Glass tube for same	27	0.34
2. Single needle, large	25	0.45
Glass tube for same	21	0.70
3. Double-barrelled needle	30	0.27
	30	0.27
Glass tubes for same	24	0.50
	24	0.50

PLATE XVI.—OPERATING STEEL NEEDLES AND BEDS

This plate shows some steel operating needles and the beds for them.

I. The pilot needle with its bed in which it is kept mounted as it is always required.

II. The horizontal cyclotome mounted on a bed which serves for the other forms of cutting needle shown at III and IV, and a fine tube (V) provided with a funnel and a rod which fits it and is used for introducing drugs.

III. Orthotome.

IV. Dr. Mussen's spherotome.

V. Fine steel tube for introducing drugs.

PLATE XVI, A

A drawing of an improved form of bed for these cutting needles which has not been constructed yet.

PLATE XVII

Separate drawings of some of the cutting needles at present constructed.

The instruments enumerated above must now be described more fully.

PLATE XVI.—OPERATING NEEDLES AND BEDS

1. The Pilot Needle.—It is advisable that the introduction of all insulated or cutting needles should be preceded by a plain steel needle of slightly greater caliber than that which follows; it makes a smoother track, is less easily deflected than glass needles, and if membranous structures are encountered, this is important; the dura can be perforated without an incision and, on the whole, it contributes to smaller lesions and greater accuracy. Two or three sizes should be available and a suitable one fixed in the clamp on the special bed shown in the illustration. After the pilot has been introduced, it is withdrawn, the bed removed from the inner sheath and a special needle already mounted on its bed substituted.

2. Cutting Needles.—These are hollow steel needles such as are used for hypodermic injections, but with blunt points. A wire or fine watch-spring knife can be projected a few millimeters from a slot near the point, and then by rotating the needle, or projecting or retracting it a short distance, various small localized lesions or

incisions can be produced. The smallest needles of this kind which I have used are 1 mm. in diameter and the knife can be projected 4 mm., cutting a disc when rotated of 9 mm. in diameter and of any size below this. But for some purposes the finest hypodermic needles from which a steel wire can be projected 2 or 3 mm. may be employed, and very precise and restricted lesions can be produced in deep structures like the central ganglia with such trifling injury that it can be ignored and the conditions apart from the lesion regarded as normal.

The following varieties of these needles are available at present:

1. **The Horizontal Cyclotome.**—(Pl. XVI, II.) A fine watch-spring is projected almost horizontally from a slot in the side of a needle, 1 mm. in diameter, close to its extremity. The knife can be projected any distance up to 4 mm. and when rotated cuts a disc perpendicular to the needle of any diameter up to 9 mm.

2. **The Vertical Cyclotome.**—(Pl. XVII.) This can be made of various sizes in accordance with the object for which it is required. A hollow needle, 1 mm. in diameter, is divided by a longitudinal incision for from 2 to 5 mm. from its extremity, a flat watch-spring knife, slightly shorter than the incision which it occupies, is pivoted about its center by a small rivet; the wire which passes down the needle is pivoted to the proximal end of the knife. When introduced, the knife is entirely concealed in the incision, in which it lies parallel with the needle; by pressure on the wire, the knife is made to rotate upon its pivot until it projects at right-angles to the needle, an equal distance on both sides of it. In reaching this position it cuts two diagonal quadrants and by retraction of the wire the knife regains its original position; the needle is then rotated half a turn and the knife again projected till it is horizontal; it thus cuts two other diagonal quadrants complementary to the first and completes a disc the plane of which is parallel to the axis of the needle, the diameter being the same as the length of the knife.

3. **The Orthotome.**—(Pl. XVII, 137) is like the last, but instead of the knife being pivoted on its center, the rivet is at the distal end, and when pressure is applied to the wire the knife projects horizontally from one side of the needle and in its movement to this position cuts a quadrant; if the needle is projected or withdrawn a few millimeters the knife makes a linear incision of its own length parallel with the needle.

4. The Spherotome.—(Pl. XVII, 138) designed by Dr. Aubrey Mussen. Here a steel wire ending in a watch-spring knife is introduced into a hollow needle. The extremity of the knife rests in a slot close to the end of the needle and is there pivoted with a rivet; one side of the needle for a few millimeters from its end is filed away to expose the watch-spring which bulges outwards in the form of a bow when pressure is applied to the wire. By rotating the needle when the spring projects, a spheroidal figure is cut, the size and shape of which depend on the length of watch-spring exposed and the pressure applied to it.

5. Fine Steel Tube for Introducing Drugs, etc.

I. Pilot Needle Bed.—This needle has no movement but linear projection and retraction; it is therefore clamped (120) to a brass plate with a rack along the right edge which fits the inner sheath (93) of the holder (Pl. XVI) and can be projected by the racked and sliding movements described. It is provided with an adjustable index (113) on the right for reading the rectilinear scales and a millimeter scale (110) on the left for inclined movements. A screw head (118) serves as a handle for introducing it or removing it from the inner sheath.

II. Bed for Cutting Needles.—For all these needles the same linear projection movement to direct them to any required point in the brain is necessary and is provided for by the same means; *viz.*, a brass plate fitting the inner sheath and with an adjustable index and scales similar to those which have just been described with the pilot needle. But when these needles have reached their destination some mechanism is necessary for their special purpose, such as projecting a concealed knife a short measured distance, rotating the needle and knife a half or a full turn and then retracting the knife before withdrawing the needle. The bed which is at present employed for this purpose is shown in Plate XVI, II. A design for an improved pattern is shown in Plate XVIA, but owing to the war it has not been possible to get it made. It will be necessary to describe both patterns, beginning with the one in use.

Plate XVI, II. The inner sheath and scales are the same as those in Plate XIV and these parts are indicated by the same figures. The brass bed similar to that of the pilot needle will also be recognized and the projection of the concealed knife and the rotation of the needle are effected by the following arrangement. The operating needles

shown in Plates XVI and XVII have the same construction and consist of:

(1) A hollow steel needle about 1 mm. in diameter with an opening close to the distal end through which the concealed knife (7) is projected and terminating at the proximal end in a brass cylinder (2), about 2 mm. in diameter and 10 mm. long, terminating at both ends in milled discs (3 and 9). These parts are united and rotation of the discs rotates the cylinder and needle also. The cylinder is prolonged above the disc (3) and graduated in mm. (4). A second rather larger cylinder (5) screws over (4) and its lower margin serves as an index to read the graduations on (4). The cylinder (5) is screwed down by the milled disc (6) and carries a wire which passes down the hollow needle and is attached to the knife (7). Consequently, when the cylinder (5) is screwed down, it projects the knife and at the same time its lower edge shows on the graduations at (4) the distance the knife is projected. The cylinder (2) is held by a clamp (119) fixed to the bed, the pressure of the clamp is regulated by a screw; the friction should be sufficient to hold the cylinder firmly, but not to prevent its rotation. The two milled discs (3 and 9) prevent any slipping in the axis of the needle which passes through the stop (97).

The projection of the needle is measured and the adjustable indices set by the stop in the same way as with the glass needle explained under Plate XIV, and a mark on the disc (3) shows the direction in which the knife is projected; *i. e.,* it corresponds to the opening in the needle. Before the needle is introduced, the knife is withdrawn so that its extremity is flush with the opening in the needle and the scale at (4) is noted. When the needle has reached the required point in the brain the disc (3) is rotated till the mark on it faces the direction in which the knife should be projected; then the disc (3) is steadied with a finger of the left hand and the disc (6) rotated with a finger of the right, causing the cylinder (5) to travel down on (4), the scale showing the excursion of the cylinder (5) and the distance the knife is projected. If it is necessary to rotate the knife and needle, this is effected by rotating the disc (3), the mark on which shows the amount of rotation, usually a half or a full turn being required. The operation having been completed, the knife is retracted by repeating the above procedure in the reverse direction and the needle can then be racked out and removed. There is no great difficulty about this

procedure, but the method of holding one disc and rotating the other, the regulation of the friction of the cylinder and the recognition of the position of the knife under all circumstances are points which admit of improvement and in these respects the plan adopted in the design XVIA is more convenient, the application of various needles of different sizes is simplified, the movements are more precise and effected more easily and the position of the concealed knife can always be recognized immediately.

Plate XVIA

Design for Improved Bed for Cutting Needles.—It consists of the brass plate (1) fitting the inner sheath and furnished with an adjustable index (2) and scale (3) already described and two structures which may be called cradles, inner (6) and outer (5); they are elongated narrow brass plates with the ends turned up at right-angles to form three sides, the bottom and two ends, of a narrow oblong box; the outer (5), considerably larger, is fixed to the bed (1); the inner (6), supported by pivots (11, 29) in slots (13, 31) of the end plates (7, 8) of the outer cradle (5) in which it rotates. The lower of these pivots is formed by the shaft of the needle (29), held in the slot by a notched and hinged bar (32); the upper pivot is a square rod, the central rod (11), with a circular groove which fits the edges of the slot (13) and is held in place by a spring bar (14). The groove secures even rotation of the central rod and prevents any longitudinal displacement, while the spring bar, owing to the square section of the rod, without preventing rotation, checks each quarter turn, the recognition of which is facilitated by the four arms of the cross-handle (12) at the top of the central rod, but is also shown unmistakably by the rotation of the whole inner cradle.

Precise rotation of the needle is thus well provided for and the measured projection of the concealed knife is effected by an arrangement in the inner cradle. This is traversed longitudinally by the central rod (11) which is fixed to both end plates (9, 10) so that they move together; the rod carries a sliding clamp (18) which resembles the screw stopper of certain bottles; its lower end is tapered, has a screw thread (22) and ring (21). The tapered end has a longitudinal slot (20) in front and by screwing the ring up the slot this is converted into a vice to grip the proximal end of the wire (19)

which passes down the needle to the concealed knife (19). Near the upper end of the inner cradle the central rod is converted into a screw (16) for a few millimeters and a milled disc (17) works up and down it; the lower surface of the milled disc has a circular rim projecting from the circumference towards the center and fitting a corresponding groove in the upper end of the sliding clamp (18), permitting free rotation between the disc and the clamp. Owing to the square section of the central rod the clamp cannot rotate upon it, and the milled disc, when it is rotated and travels up and down the screw (16), carries the sliding clamp and therefore the wire and knife with it. The excursion is measured by an index (23) attached to the clamp and a millimeter scale (24), which is adjustable, attached to the adjacent edge of the inner cradle. As this scale is not visible when the cradle is rotated, it may be convenient to have another engraved on the adjoining edges of the disc and clamp, between (17) and (18), but it is doubtful whether this is necessary. In practice, the knife must be retracted till the end is flush with the opening in the needle at (30), and in this position the wire fixed in the slot (20) and the adjustable scale (24) set at zero; if this is done it is always easy to see whether the concealed knife is retracted and, if not, how far it projects.

Various needles of different sizes can be used with this bed; tapered hollow nozzles (25) of different sizes screw on to the lower face of the end plate (10) of the inner cradle, to engage the socket (26) of the needle. The socket has a slot (28) on the same side as the opening (30) at the end of the needle from which the concealed knife is projected and a small stud (27) on the nozzle engages this slot; it prevents slipping between the nozzle and the needle and indicates the direction in which the knife is projected.

Plates XVIII, XIX, XX, and XXI, show the application of the stage and needle in various positions to a cat's head fixed in the head-vice and cage.

Plate XVIII. Needle in first position above head. Vertical.

Plate XIX. Needle in first position above head. Needle inclined to left.

Plate XX. Stage and needle applied to left of cage, sixth position, needle inclined.

Plate XXI. Stage and needle applied to rear face of cage, seventh position, needle horizontal.

CHAPTER V

ILLUSTRATED DESCRIPTIONS OF INSTRUMENTS (Continued)

Scales and Measurement of Movements of Needle, Gauging and Drilling, Methods and Applications, Charts and Microscopic Sections

A review of the preceding pages suggests that certain details, such as the measurement and corrections of the movements of the needle, which have appeared in different sections, might gain something in clearness if they were collected into a single description where they can be compared and studied together. This involves some repetition, but is preferable to ambiguity or obscurity in what purposes to be a laboratory guide rather than a book for the study. A student intending to use these instruments for experimental work needs to be familiar with all their details and on that ground may tolerate repetition which would otherwise be tedious, while, on the other hand, those who have found the preceding descriptions sufficient need not devote more attention to what follows than they consider desirable.

The scales of the needle appear confusing to those who are not familiar with them. One cause of this is that as the cost of the equatorial and indicator at present makes it difficult to bring the complete intrument within the reach of everyone, it is necessary to consult the convenience of those who purchase the cheaper form of rectilinear instrument to begin with and desire to procure the additional parts subsequently. For them it is a consideration that the same needle-holder should be available for both instruments, though the methods of measurement cannot be identical. There are some slight alterations in the pattern illustrated here which will be adopted in future and which it is advisable to explain.

Needle-Holder.—The holder now in use has been described (Chapter IV) and illustrated (Pls. XIV, XVI). Originally designed for the rectilinear machine, it was subsequently adapted for use with the indicator and has been lengthened since the illustration was prepared. It serves its purposes satisfactorily, but may be further simplified and improved by some trifling alterations. The movements and the

methods of measuring and recording them, which depend upon the mechanism of the holder, are all connected with the projection of the needle. The other movements are effected by the equatorial (Pl. XXIX) or in the rectilinear machine by the two movements of the traversing stage (Pl. XIII). They are explained in the descriptions of the instruments referred to, but the essential points will be recapitulated here.

Equatorial.—In the equatorial (Pl. XXIX) the inner sheath (93) of the needle-holder fits and slides in an outer sheath (72) which is pivoted to the carrier (44), a slide block which travels on the arch (40) of the equatorial. With the projection of the needle from the holder, to be more fully described immediately, the arrangement practically affords universal movement. All movements of the equatorial, including projection of the needle, are measured by millimeter scales, the corrections required for variations in the size of different heads being effected by the indicator (Chapter VI) and explained in the description of it.

Rectilinear Machine.—In the rectilinear machine the longitudinal (91) and transverse (70*a*, 70*b*) guides of the traversing stage (Pl. XIII) afford two rectilinear movements in the plane of the stage perpendicular to the needle, the projection of which completes the movement in three dimensions. The outer sheath (72) of the holder is pivoted to the carrier (71) which travels on the guides, and a quadrant (77) provides for an inclination of the needle in one plane, the movement being directed and measured by an indicator. With inclined or universal movements so directed, if the same opèrating mechanism, whether it is the equatorial or the cage and stage, is applied first to the indicator and then to the head in the head-vice, no scales except those which measure the projection of the needle are required; for in the first of the positions, if the needle has been brought to a given point in the indicator, when it is transferred to the head-vice, it must reach the corresponding point in relation to the zero planes in the head, and the scales for projection of the needle are required only to allow of the retraction of the needle while the skull is trephined and its subsequent projection to the original position. But if duplicate instruments are used, one applied to the indicator and the other to the head, every movement performed by the first instrument must be precisely copied in the second and therefore all movements must be regulated by scales. To ensure identical move-

ments in duplicate instruments, millimeter scales are sufficient. No correction for size is required, as it has already been effected in the indicator; therefore, for such movements proportional scales are never used.

Traversing Stage.—The measurement of the rectilinear movements of the traversing stage is simple. The millimeter scales engraved on the longitudinal and transverse guides have a zero near their middle and the scales are graduated on both sides of this point. Two lines drawn through these zero points parallel to the sides of the stage form a cross and when the stage is applied in any position above the cage (Pl. X), or behind it (Pl. XII), these crossed lines coincide with the crossed zero lines of a parallel lamella; *i. e.,* a horizontal lamella in the first case and a frontal lamella in the second. If the head in the machine were of standard size in both dimensions, it would obviously be easy to rack the needle the same number of millimeters from the crossed lines or zero points of the stage, as the objective is reckoned from the zero lines in the chart and in the assumed lamella of the head in the machine, and then project the needle till it reached the objective. But if the dimensions of the head in the machine are not of standard size the millimeter scales must be corrected to correspond with any variation, or proportional scales which have been set in accordance with previous measurement of the head must be employed.

Two Transverse Guides Differently Graduated.—If Plates XI and XII are compared it will be seen that in Plate XII the stage is applied to the rear face of the cage (position 7) in such a way that the zero in the middle of the transverse guide (70*b*) coincides with the upper surface of the horizontal frame or head-vice which is the level of the basal horizontal zero plane, but when the stage is applied to either side of the cage positions (5 or 6), as shown in Plate XI, owing to the position of the screw clamps and ear pivots attached to the lateral bars of the head-vice, the stage must be applied with its side resting on the horizontal frame and the zero in the middle of the transverse guide (70*b*) cannot be made level with the upper surface of the head-vice or the basal zero plane and therefore does not correspond with the basal zero plane in the chart or the head. For positions 5 and 6 another millimeter scale is engraved on the transverse guide (70*a*), graduated in millimeters from a zero level with the upper surface of the frame when the stage is applied as seen in Plate XI (position 5 or 6). This guide (70*a*) is marked *Trans.,* indicating that this

scale is used for vertical measurement when the needle is directed transversely, as it must be when applied to either side. The same extensible scale is used for both guides (70*a* or 70*b*), but a spiral is selected for zero which corresponds with the zero engraved on the scale which is used. The same index reads both the engraved and extensible scales and, if desired, an ivory millimeter scale can be attached which can be read more easily than an engraved scale, but is not indispensable. The same index reads all three scales (see Plate XIII (81)).

Direction of Needle to Objective.—Any objective point must lie in one lamella at least in all three planes and can therefore be located in a chart in any of them. One of these planes is perpendicular to the needle, the other two parallel to it. If the objective is located in the first (perpendicular) lamella, the two movements of the stage bring the needle opposite the objective, and the third movement, the projection of the needle, directs it to the required point. If the objective is defined in a lamella parallel to the needle (and with the inclined needle this is necessary), one movement of the stage carries the needle to the edge of the lamella, as if it were the page of a book; the other movement of the stage and the projection of the needle bring it to the objective point, as if this were a given letter in a given line of that page.

Rectilinear Machine. Inclined Movement.—The quadrant attached to the stage provides for an inclination of the needle in one direction and one plane. If it is desired to introduce the needle obliquely it must be directed by an indicator, as described in Chapter VI. If a single operating mechanism is employed, the cage and stage with the needle must first be applied to the indicator, the needle set at any required angle and then directed by sight to the index point and all movable parts fixed. The point to which the needle is projected is noted on its scale; the needle is then retracted sufficiently to be out of the way and the cage and stage are applied to the head-vice which contains the head, the needle projected till it touches the surface of the skull, the point marked and the cage removed while the skull is trephined. The cage is then replaced and the needle racked through the brain till the index reaches the point noted on the scale when the needle arrives at the objective point in the brain. Or, duplicate operating instruments may be employed. An indicator, in which the essential parts of the operating mechanism are reproduced, is required;

a finder needle, representing the operating needle, is set at a given angle and directed by sight with two movements to the index point corresponding to the objective. By similar scales the movements of the indicator are copied in the operating machine and the needle brought to the objective in the brain. As the inclination of the needle and the objective are in the same plane, besides the inclination of the needle, two movements and a two-dimensioned indicator are sufficient. One movement of the stage brings the needle to the edge of a lamella in the same plane as its own inclination, the second movement of the stage and the projection of the needle are sufficient to direct it to the objective.

Proportional Scales.—It is important to note that in this proceedding a proportional scale or correction for variation in the size of the selected head is required for the first movement of the stage which brings the needle to the edge of the lamella, but for the two remaining movements, *viz.,* the second movement of the stage and the projection of the needle which are directed by the indicator, a proportional scale is not employed, as any correction required must be made in the indicator.

When the indicator is employed with duplicate instruments, movements are directed by sight in one and merely copied in the other; or, if the operating instrument is first applied to the indicator and then to the head, the only scale required is that which shows the projection of the needle, and for this, one mark would suffice to indicate the point reached in the indicator, so that the original position could be regained after the needle had been retracted for trephining the skull. In rectilinear movements, and in these only, the position of any point in the brain in relation to the zero planes is ascertained in the chart and directly measured in the brain by the scales of the instrument. The distance of an anatomically identical point from a zero plane in two heads of the same species of animal is not necessarily the same, but roughly proportional to the size of the given dimension of the heads; therefore, whenever the scales of the instrument are used to measure a point in the brain from a zero plane in accordance with a chart, proportional scales or correction are necessary, but measurements of movements of the instrument for comparison; or of the length of the needle, are not affected by the size of the head and are always recorded in millimeters.

In the instance just explained in which an inclined needle is directed to an objective point in the brain, the distance of the required lamella from the parallel zero plane, which is measured by the scale for the first movement of the stage, depends upon the size of the selected head, hence a proportional scale or correction is required; but with the other two movements, to copy a duplicate instrument or project a needle a given distance, a millimeter scale is sufficient. Obviously, if the inclination of the needle is not required, it can be directed to the objective by three rectilinear movements, two of the stage and its own projection. Each of these movements depends on the distance of a given point in the cranium from one of the zero planes; ascertained in the chart and measured by the scales of the machine in the selected head, in each case the distance depends upon the size of the respective dimensions of the head, and proportional scales or corrections are necessary in all of them. The cage and stage together are the counterpart of the equatorial, with a more limited range restricted to rectilinear movement in three planes and one inclined in one direction and in one plane, while in the equatorial the movements are universal. On the other hand, the former can be directed and measured by the scales of the instrument or by an indicator, while with the latter an indicator is indispensable. In either case, when the indicator is employed, the same mechanism can be applied first to the indicator and then to the head, in which case no scales but that for the projection of the needle are required. Or, duplicate instruments can be applied to the indicator and the head, all movements in the first being copied by corresponding scales in the second. Two of the three dimensional movements provided for the needle in the rectilinear instrument, effected by racking the carrier (Pl. XIII, 71) on the longitudinal and transverse guides (70, 91) of the stage, having been explained, the third, the projection of the needle perpendicular to the stage, now requires consideration. It is necessary, for reasons which have been stated, that the same needle-holder should be available for use with both the rectilinear machine and the equatorial, and as it is not practicable to adopt the same method of measuring the excursion of the needle in these instruments, two sets of scales on the same holder are required which appear confusing until they are understood.

Measurement of Projection of Needle.—In the rectilinear machine measurements are made directly from the central zero planes of the cranium which coincide with the zero points of the instrument; all

scales are graduated from these points to show the distance of the needle from them. Scales for rectilinear projection register the distance of the point of the needle from the zero plane to which it is perpendicular, and when the index reaches zero on the scale, the point of the needle is at that zero plane. With the equatorial, or any needle inclined at various angles, it is not practicable to indicate the distance of the point from central zero planes in this way. Another instrument, the indicator, is employed, in which the needle is directed by sight to a point representing the objective, and the movements are identical with those in the operating instrument in which they are repeated by corresponding scales. Here the scales for the projection of the needle are required only to ensure correspondence of the duplicate instruments and that the needle is projected the same distance in both, its length being measured in millimeters from the point to the pivot on which it is inclined. Thus we have a scale for rectilinear movements, on the right, which records the distance of the point of the needle from the zero plane to which it is perpendicular, and the indicator scales for inclined movements, on the left, showing the length of needle projected from point to pivot.

Single and Separate Scales.—Whether they are rectilinear or inclined, two projection movements are provided: one, a coarse adjustment, by sliding between the sheaths; the other, or fine adjustment, by racking the bed with the needle in the inner sheath; and they can both be recorded on the same, or on separate scales. Each method has certain advantages. A single scale is more simple, and as different scales are required, in any case, for rectilinear and inclined movements and it is not desirable to increase their number, for an instrument of the present size, large enough for a full-sized rhesus monkey, the single scale is preferable. To meet every possible inclined position, however, the scale should be about 9 cm. long for the rhesus or a good deal more for larger heads, and this might be inconvenient; hence, the details of both methods should be considered. In the needle-holder shown in Plate XIV which was gradually evolved with the instrument, both methods are illustrated, separate scales being employed for rectilinear movements, on the right, and a single one, for the inclined needle, on the left. For descriptive purposes it is convenient that both methods should be illustrated, but for the future, whichever is selected, it will be better to adopt the same on both sides.

A distinction to be specially remembered between the rectilinear and inclined scales is that, with the former, the distance of the objective, or any point in the cranium, from the zero planes is directly measured by the scales and, therefore, as heads vary in size, the measurements must be proportional, if they are to correspond with the charts. The engraved scales of the instrument are in millimeters, which are only applicable to heads of standard size; for others, corrections must be made or proportional scales introduced; the latter method is more convenient and one of the extensible scales described (Pl. IX, Chapter IV) is attached to the millimeter scale (Pl. XIV, 112) and both are read by the same index, which thus records the distance of the needle from the zero plane in millimeters and coordinates proportional to the size of the head. The scale of the inclined needle (110), on the left, is not employed for direct measurements of the cranium; these have been made and corrected in the indicator, the movements of which are exactly repeated in the operating instrument, for which purpose it is sufficient to know the length of needle projected, from point to pivot, in millimeters and be sure that it is the same in both instruments.

Adjustable Index.—Another detail is the adjustable index which is required with both scales if glass needles are used. As the point of the needle is a base of measurement in both methods, its position in precisely defined relation to the index is important and the needle must be exactly the right length or its index adjustable. If a glass needle happens to break in the course of an operation and a new one is substituted quickly, it is difficult to secure absolute accuracy and much more convenient to use an adjustable index which within certain limits can be adapted to a needle of any length. Such an index is, therefore, provided on both sides.

The details of the various scales for directing and measuring the projection of the needle which have been referred to will be considered under the following heads:

1. To begin with, a summary of the requirements which are essential in a needle-holder intended to direct and measure the projection of the needle with the rectilinear instrument or the equatorial.

2. An explanation of the way these requirements are provided for in the present holder (Pl. XIV).

3. A short description of alternative methods of registering rectilinear or inclined movements with coarse and fine projection which are recorded on a single or on separate scales.

4. The pattern recommended for the future.

1, a. The first requirement is an arrangement of scales, by which the same needle-holder will serve for the two methods of measurements employed with the rectilinear instrument and the indicator.

1, b. Secondly, each scale must be provided with an adjustable index to correct differences in the length of needles, especially of glass ones.

1, c. Thirdly, in each case, two extension movements of the needle are required: (1) A coarse adjustment, effected by sliding the inner in the outer sheath, to bring the stop up to the skull; and (2) a rack and pinion extension for projecting the needle into the brain. These two movements can be registered by a single scale and index, or two; the former has the advantage of simplicity, but the mechanism for the latter is more compact.

1, d. Lastly, if extensible scales are used for making corrections for size, they are required only for rectilinear measurements of the cranium and must be attached to the scale which records them.

Next, to explain how these requirement are provided for in the holder which is shown in the illustration.

Needle-Holder.—In the needle now used and shown in Plate XIV the scales for the rectilinear instrument are on the right; the coarse and the fine rectilinear projection are directed and measured by two scales: (1) *The scale of the stop* and (2) *the scale of the needle.* The former registers the sliding movement between the sheaths by a scale and arrow on the adjoining borders of the inner and outer sheaths on the right of the holder (See Pl. XXIX, 72, 93). The latter, the excursion of the needle through the stop effected by racking the bed in the inner sheath. This movement is recorded by an adjustable index (113) attached to the right edge of the bed and a millimeter (112) and extensible (111) scale fixed to the inner sheath. With rectilinear projection the scales record the distance of the stop or the point of the needle from the zero plane to which the needle is perpendicular. The stop being the termination of the inner sheath, sliding between the sheaths, carries the stop and needle to and from the zero plane; the stop and the zero points which define the zero planes are parts of the instruments and therefore constants, for the measure-

ment of which no proportional scale is required. An arrow on the side of the inner (93) and a millimeter scale on the adjoining border of the outer sheath (Pl. XXIX, 72) show the distance of the point of the stop from the zero plane, and when the arrow reaches zero on the scale, the stop is at the zero plane. In practice, however, the stop cannot go beyond the surface of the brain; hence, the scale need not be graduated to zero, but not more than 10 millimeters can be dispensed with in case it might be required to reach the surface of the cerebellum in small animals. To give the needle as much support as possible, the stop is pushed into contact with the surface of the brain by its sliding movement and fixed with the screw (96). The scale of the stop on the outer sheath is then read by the arrow showing the number of millimeters from the stop to the zero plane. The objective is reached by racking the needle through the brain and the excursion recorded by the adjustable index on the bed and the scales on the inner sheath. The stop having reached the surface of the brain, its share of the movement is over, the rest is effected by the needle, the scale of which must be set to correspond with that of the stop. The first step is to make the point of the needle level with that of the stop, a position easily recognized by sight or touch; the distance from the stop to the zero plane in millimeters is known and the adjustable index is set at the same figure on the millimeter scale of the needle. An extensible scale, (111) previously set in accordance with the measurement of the head, is fixed in clamps besides the millimeter scale so that their zero points coincide, the index reads them simultaneously and as it is racked in, continues to indicate the number of millimeters and coordinates between the point of the needle and the zero plane; and when this is reached, the index is at zero on both scales. As it may sometimes be necessary to project the needle beyond the zero plane, the scale of the needle is graduated for 10 mm. below zero.

Extensible Scales.—It will be noted in this description that an extensible scale is employed with the scale of the needle, but not with that of the stop; the selection of these scales presents some difficulty to the beginner and.must be made as clear as possible. An extensible scale is not required with the scale of the stop because the stop and the zero points are constants of the instrument, unaffected by variations in the size of the head; the scale is required to show the distance from the stop to the zero plane of the head, but as this coincides with

the zero plane of the instrument, it is a constant also; there is no question of proportional variation; it is a direct measurement of the instrument expressed in millimeters and recorded by permanent scales.

When the stop has reached the surface of the brain and its excursion is ended, by setting the adjustable index on the scale of the needle, the latter is made identical with the stop and the scales continuous, so that the separate scales are united to form a single one which registers the whole excursion of the stop and needle without a break. It indicates the distance of the needle substituted for the stop from the same zero plane; these points are still constants and so far there is no question of proportional measurement. But now a new factor is introduced; the needle must be directed to an objective in the brain, the distance of which from the zero plane has been ascertained in divisions of the scale of the chart and these are coordinates proportional to the size of the head represented. Since the size of the head in the machine is also variable and the corresponding point cannot be found by measuring an equal number of millimeters, it is necessary to use a scale, the divisions of which have been corrected for size like those of the chart, or a millimeter scale corrected by calculation. The proportional scale is most convenient; the needle can be racked till its index records the same number of divisions of that scale from zero as have been counted from the zero plane on the scale of the chart. Here the distance of the objective point in the brain from the zero plane, which varies with the size of the head, is directly measured by the needle and a proportional scale is required. It is only with the rectilinear scale that the distance of a point in the brain from the zero plane, which varies with the size of the head, is directly measured by the needle in this way, and therefore it is only with the rectilinear scale of the needle that a proportional scale is required; with all others the measurements are in millimeters. This has been explained in the case of the rectilinear scale of the stop, and the indicator scales on the left record only the length of the stop or needle projected from the pivot. These are parts of the instrument; they are not required to measure a variable point dependent on the size of the head and they are always measured by millimeter scales.

Indicator Scale.—In the illustration (Pl. XIV) it will be seen that with inclined movements both coarse and fine projection of the needle are recorded on a single scale, which is engraved on the left side of the bed (110) and read by an adjustable index (Pl. XIII, 79)

attached to the outer sheath. To provide for all oblique movements of the needle in the head of a large rhesus the scale should be 9 cm. long (it has been lengthened in the holder represented, since the plate was prepared). The scale of the stop is abolished, both the sliding movement between the sheaths and the racked projection of the needle being recorded on the millimeter scale (110) which shows the length of both stop and needle projected from the center of the pivot in millimeters.

The essential difference between the *rectilinear* and *indicator scales* is that the former are required to show the distance of the point of the needle or stop in any position from the zero plane to which they are perpendicular, while the latter record the length of needle or stop projected from the pivot; consequently, with rectilinear scales the projection is towards zero and the index travels down a descending scale, whereas with the indicator scales the movement begins at zero when the needle and stop are level with the center of the pivot, and the projection of either stop or needle carries the index up an ascending scale of figures. All inclined movements are recorded in millimeters and an extensible scale is not required.

Adjustable Index.—An adjustable index is required for needles of variable length and must be set at the outset as follows: The needle is racked down till its point is level with that of the stop, which is then brought opposite the center of the pivot by sliding the inner sheath till the *P. S.* line on the back of it is level with the top of the outer sheath and the index is set at zero on the scale. In practice, the stop is then moved into contact with the surface of the brain by sliding the inner in the outer sheath; here it is fixed and the needle racked through the stop and brain till it reaches the objective. Both movements are recorded on the same scale, the index showing the total length of needle projected—differing from the rectilinear scales where the index starts at the maximum figure, which is reduced by the excursion of the stop, leaving the remainder to be effected by the racked movement of the needle. It appears rather an arbitrary arrangement that with the rectilinear scale of the needle on the right the scale should be attached to the inner sheath and the adjustable index to the bed, while on the left the scale is on the bed and the index attached to the outer sheath. This is merely a matter of mechanical convenience; the milled head which racks the bed in the inner sheath must be on one side or the other. Here it is on the right, it occupies some space,

and on that side it is more convenient to attach the adjustable index to the bed; on the other side, where the whole length of the bed is free, it is preferable to have the scale engraved on it.

Single and Separate Scales.—It will be desirable in future, whether coarse and fine projection are recorded on a single or separate scales, to adopt the same method on both sides—the single scale is preferable with small heads not larger than that of a rhesus. For larger ones, it will probably be more convenient to use separate scales. There are four methods of recording rectilinear and inclined movements with single or separate scales:

Rectilinear Movements. Right Side.	1. Coarse and fine projection recorded on a single scale. 2. Coarse and fine projection recorded on separate scales.
Inclined Movements. Indicator Scales. Left Side.	3. Coarse and fine projection recorded on a single scale. 4. Coarse and fine projection recorded on separate scales.

2 and 3 have been described; the arrangements for 1 and 4 are as follows:

1. Rectilinear Movements.—Coarse and fine projection recorded on a single scale. Right Side. Not shown in the illustration:

An adjustable index is attached to the right side of the bed. A millimeter scale, 9 cm. long with an extensible scale beside it, is fixed to the outer sheath, so that their zero points coincide. Both scales are read by the same index. The zero is central, *i. e.,* towards the point of the needle, so that, as this is projected, the index travels down a descending scale and is at zero on both scales when the needle reaches the zero plane to which it is perpendicular. The adjustable index is set at the outset as follows: The distance from all surfaces of the cage to the parallel zero plane is the same, so that in any position of the stage the distance of a fixed point, such as the center of the pivot of the outer sheath from the zero plane which is perpendicular to the needle, is a constant, *viz.,* 70 mm. We therefore make the point of the needle coincide with that of the stop and the latter level with the center of the pivot by bringing the top of the outer sheath to the *P. S.* line of the inner sheath and set the adjustable index at 70 on the millimeter scale. The point of the needle is therefore 70 mm. from the zero plane and, as either stop or needle is pro-

jected, the index shows the number of millimeters between the point of the needle and the zero plane, and at the same time the equivalent number of coordinates on the extensible scale which is set in accordance with the measurement of the selected dimension of the head in the machine. The stop is pushed into contact with the surface of the brain, the number of divisions between the objective and the zero plane are noted in the chart, and the needle is racked to the same number of divisions of the extensible scale from zero, when the point of the needle will reach the objective. If an extensible scale is not available a millimeter scale can be used, but the number of millimeters from the zero plane to the objective must be corrected in proportion to any variation in the size of the dimension of the selected head from the standard.

4. Indicator Scale. Left Side. Separate Scales (not shown in the illustration). Here the sliding movement between the sheaths, coarse projection, is registered by the scale of the stop, a millimeter scale engraved on the left side of the outer sheath read by an arrow on the adjoining border of the inner sheath. While the racked projection of the needle through the stop is recorded by the scale of the needle, which is also a millimeter scale engraved on the left of the bed, it is read by an adjustable index attached to the inner sheath. The first of these scales indicates the distance of the point of the stop, and the second the point of the needle, from the center of the pivot. The two scales are coordinated and the adjustable index set in the same way as the separate rectilinear scales. The points of the stop and needle are made to coincide; the inner sheath is pushed in until the stop is in contact with the surface of the brain, and fixed, the number of millimeters it is projected from the pivot is read on the scale of the stop and the adjustable index set at the same figure on the scale of the needle. In both scales the index traverses an ascending scale of figures beginning with zero, and as the needle is racked through the brain, it continues the scale from the point where the scale of the stop terminated and so registers the total projection of the stop and needle from the pivot. It is not necessary that the scale of the needle should be graduated below 20, as the stop must always travel that distance from the pivot to reach the skull; the length of the scale of the needle is therefore diminished to that extent. As both scales are required to show the length of needle and stop projected from the pivot, and as this is an intrinsic measurement of the

instrument, all records are in millimeters and no proportional scale is required.

Summary.—In the preceding description the details to be specially noted are the following:

The rectilinear scales show the distance of the stop or needle from the zero plane; the indicator scales, the distance of the same points from the pivot. Both these are measurements of the instrument and could be recorded in millimeters. But the rectilinear scales of the needle are also required to identify the position of the objective point in the brain by indicating its distance from the zero plane in terms of the chart where the nominal millimeters are coordinates. Therefore, this distance must be recorded not in millimeters, unless the dimension involved is of standard size, but in coordinates or corrected millimeters, proportional to the size of the dimension compared with the standard. If the correction is made by calculation, a millimeter scale can be used; otherwise, an extensible scale is necessary.

Lastly, the adjustable index must be set to correspond with some constant. With separate scales on both sides the coarse projection is recorded by the scale of the stop. Here the sliding movement between the sheaths is completed before the index of the needle is set; then, the needle and stop having been made to coincide, the adjustable index is set at the same figure on the scale of the needle as the arrow shows on the scale of the stop; in other words, the scale of the needle is made a continuation of the scale of the stop. The constant in this case is the scale of the stop. With single scales, on both sides the scale of the stop is abolished. Both coarse and fine projection are recorded on the scale of the needle and the adjustable index must be set at the outset. The points of the stop and needle having been made to coincide, the stop is made level with the center of the pivot by bringing the *P. S.* line on the inner sheath to the top of the outer sheath. Then on the rectilinear scale the adjustable index is set at 70, on the indicator scale at zero. In the former, with any projection of either stop or needle, the approach to the zero plane is recorded towards zero on a descending scale; in the latter, similar movements are recorded from the pivot which is represented by zero on an ascending scale. The constant here is the pivot which is 70 mm. from the zero plane parallel to the stage and perpendicular to the needle.

The best pattern for the needle-holder in future appears to be one similar to that illustrated, but with an instrument suitable for heads

not larger than that of a rhesus it will be advisable to employ single scales, 9 cm. long, for coarse and fine projection on both sides as described (1 and 3).

Gauging and Drilling. Methods and Application, Charts, Microscopic Section, Frontal Sinus in the Cat

In some respects it would have been advantageous to include the following description in the second chapter, as the topographical data, upon which operative procedure is founded, depend upon the accuracy of the methods of measurement, and some knowledge of these methods is required for a complete estimate of the topographical principles and their application.

But, as the instruments employed for gauging and drilling are attached to the head-vice and cage, it was necessary to describe the latter first and, having carried the description of the rectilinear instrument so far, it was undesirable to interrupt it with an account of the procedure, which will now be explained.

Gauges and Drills.—Accurate measurement of the cranium of a living animal is a matter of some difficulty; the method described here has gone through several modifications and has, I hope, reached somethink like finality. Not mathematical accuracy, which is impossible with such irregular and in some parts yielding structures, but it is probably as near it as the conditions permit; the unavoidable errors are small, the procedure simple and fairly quick and there should be no serious mistake.

Formerly, with the rectilinear machine, measurement of the cranium was effected by a depth gauge with a needle-point applied to the free surfaces of the cage. This is shown in Plates XXII, XXIII and XXIV. For drilling, a rectangular frame, carrying drill guides, was applied to the cage in three positions shown in Plates XXXI, XXXII and XXXIII. The procedure was simplified and improved in the combined gauging and drilling cage (Pl. XXXIV) which is more satisfactory for both purposes.

It may be objected that the special cage is cumbersome and some simpler instrument might serve the purpose; several have been tried without much success. All forms of calipers are untrustworthy, but the modified depth gauge with a needle and cap (Pl. XXII) answers the purpose, if care is taken to ensure its application to correspond-

ing points in all cases. As a slight difference in the direction of a diameter may cause appreciable error, the needle must be perpendicular to the zero plane and in addition to this it requires a cage and cannot be used with the equatorial. So, for those who have already procured the rectilinear machine and the cage which belongs to it, this gauge may be recommended, but anyone who has the equatorial and would have to obtain a cage, as well as the needle gauge, had better obtain the combined drilling and gauging cage complete.

The same remarks apply to the matter of drilling. If it is resorted to only occasionally, the detachable frame (Pls. XXXI, XXXII, XXXIII) applied to the cage of the rectilinear machine will serve the purpose of those who have the latter instrument and save the expense of the special cage (Pl. XXXIV). Illustrations of this frame are given, but the special cage is much more satisfactory.

The Needle Gauge.—(Pls. XXII, XXIII, XXIV.) The illustrations and explanatory notes make a lengthy description of this gauge unnecessary and its application is further explained in the account of the measuring cage which follows; the only difference being that, instead of guides to direct a needle gauge permanently attached to six sides of a special cage, there is a needle gauge (136) mounted on a sliding joint (142) on a base bar (131), with two sliding feet (132) which can be applied to any surface of the ordinary cage of the rectilinear instrument.

The gauge shown in the illustrations was graduated for use with a cage in which the three diameters were different and the adjustable index (139) had to be set for each. There are two scales on the gauge. One (134) reading from the needle is employed only for setting the index; the other (135) is employed for measuring the cranium. The measurements on this scale are reckoned from the point of the cap (138) when it is screwed up (136); in this position, the point of the needle (137) is exactly flush with the point of the cap and therefore the point of the needle or of the cap serve as the zero of scale (135) read by the index (139). To set the gauge, the figures engraved on the foot (132) are required, the number selected depending on the dimension to be measured, *i. e.,* transverse, longitudinal or vertical. The index (142) is brought to the figure given on the foot (132) for the required diameter on the scale (134) and fixed with a screw not seen in the photograph; the index (139) is then set at zero on scale (135) and fixed with the screw (141). When it has been set

in this way, if the gauge is applied to the cage in the required diameter, the point of the cap or needle will be at the zero plane to which it is perpendicular (Pl. XXII). If the screw which fixes the gauge is then relaxed and the gauge applied to a head in the cage (Pl. XXIV) and the needle made to penetrate the integuments to the bone, the index (139) shows on scale (135) the distance in millimeters from the zero plane to the surface of the bone. In the example shown, the object is to measure the vertical diameter of the cranium from the basal zero plane to the vertex. The figure given at (132) for the vertical diameter is 52, so the index (142) is brought to 52 on the scale (134) and fixed and the index (139) set at zero on the scale (135). If the gauge is then applied to the cage so that the needle is directly over the point where the sagittal and frontal zero planes intersect, the point of the needle will be at the interaural line (Pl. XXIII). The fixing screw is relaxed and the sliding gauge (136) withdrawn sufficiently to apply it to the head in the cage (as shown in Pl. XXIV), the needle is pushed through the integuments up to the bone and the index (139) is seen to be at 30 on the scale (135). The distance from the basal zero plane to the vertex at the selected point is, therefore, 30 mm. in this head. In future, with a cage in which the three diameters are identical, it will not be necessary to set the gauge for any diameter—the adjustable index and second scale will not be required. It will only be necessary to apply the gauge to the head (as in Pl. XXIV) and the index (142) will show on a single scale on the sliding gauge the distance of the surface of the bone from the zero plane in any diameter.

Drilling.—The use of the drill has been explained in the account of the preparation of chart sections in the first part of the atlas and will be described again in this chapter. In all sections of the cranium in any plane, the position of the other two zero planes is indicated by crossed lines and these are defined by three drill punctures in a line, the drill being perpendicular to the plane of section. The central puncture is made at the intersection of two zero planes; the others 10 mm. on each side of it. A line connecting the three punctures represents one of the zero planes in section and a second line through the central puncture, at right-angles to the first, represents the other. It is desirable that a drilling apparatus should be available, as the only charts published at present are those of the cat. The first part of the rhesus is issued with this description, but if any other species of ani-

mal is used for investigation, the experimenter must prepare his own charts; not necessarily a series, a few sections may suffice, but these must be prepared in the usual way. For topographical purposes, also, such as the localization of a lesion, a drill is often useful and lastly, although, with care, accurate measurements can be made with a needle gauge applied to the ordinary cage, it is more satisfactory to make them with the special apparatus.

Gauging and Drilling Cage.—(Pl. XXXIV.) Of the two purposes of this instrument, drilling requires most attention, as it presents greater difficulties; and while a drilling cage can always be adapted for gauging, the converse may not be true, as an efficient gauging instrument might not be rigid enough for the drill. Gauging, however, must be practised in living as well as in dead animals, whereas drilling is, of course, only employed with the latter, and, as a rule, with heads which have been separated from the body. With a rigid frame and adjustable guides, regulated by scales, the drill is directed through the cranium in any of its three diameters. Three punctures are made in a line at measured intervals, in the zero planes which they define, vertically and transversely in the frontal, and longitudinally in the horizontal zero plane. To define the zero planes accurately the head must be adjusted in the head-vice, to which a cubical skeleton frame, similar to the cage of the rectilinear machine, but stouter and heavier, is applied. It is provided with feet and bolts like the ordinary cage and engages the same slots, and adjustable drill guides in opposed pairs are fitted in slide blocks (5, 6, 17, 18, 23, 23) to the six sides of this cage. The drill guides proper (7, 8), as distinguished from the slide blocks which carry them, are cylindrical rods 6 mm. in diameter, bored in their long axis for the drill and themselves fitting cylindrical slots in the slide blocks which travel on the graduated guides (1, 2, 3, 4, 15, 16) of the cage. The movements of the slide blocks are regulated and any pair of them can be accurately adjusted, at opposite points of a selected zero plane, by the scales on the traversing guides, and the blocks can be fixed in any position with screws. The cylindrical drill guides also slide in their slots and can be pushed into firm contact with the cranium and fixed with screws, the object being to give the drill as much support as possible and especially to prevent it from slipping, where it engages an oblique surface of bone. The drill is introduced first on one side of the head

and then on the other and then a long needle (32) is passed through the cranium from guide to guide.

The traversing guides, which carry the slide blocks and drill guides, are fitted to the cage as follows: Four bars (1, 2, 3, 4) graduated in millimeters and each carrying a slide block (5, 6, 23, 23) form a rectangular frame, which is fixed over the cage in the frontal plane just in front of the frontal zero plane, so that the centers of the slots of the slide blocks coincide with the zero plane above, below and on both sides. This frame is permanently fixed to the cage and, in order that the latter may be lowered over the head, the inferior guide (4) of the drilling frame is detachable. The other three sides of the frame are fixed astride the cage, which is applied from above over the head; four feet with bolts (67, 68) fit the slots of the head-vice and are firmly locked. The lower detachable guide terminates at both sides in joints (13, 14) which fit over the extremities of the vertical guides (2, 3) of the frame and are fixed with screws, thus completing the quadrilateral frame for vertical and transverse drilling. For the former, the upper and lower slide blocks are brought to zero, which is the middle point of the transverse guides, and in this position the centers of the drill guides coincide with the intersection of the sagittal and frontal zero planes. The head is drilled here, and this is the center of the three vertical punctures; the slide blocks are than moved successively 10 mm. on both sides of this point and the drilling repeated, completing the three vertical punctures in the frontal zero plane. For transverse drilling in the same zero plane, the lowest of three punctures in a vertical line is made through the ear pivots, which are bored for this purpose (31, 31); the next puncture is made through the drill guide at the level of the horizontal zero plane; and the third at the same distance above the second. The mid-horizontal zero plane is not a constant, being one-third of the distance from the meatus to the vertex in the cat and one-fourth of that distance in the monkey. The punctures are made at corresponding intervals by the adjustment of the slide blocks on the scales of the vertical guides of the frame. As this drilling frame is fixed in the frontal zero plane, which is a constant, no longitudinal adjustment is necessary. A single movement on the transverse guides for vertical drilling and on the vertical guides for transverse drilling is sufficient to bring the drill to any of the points indicated. But, as longitudinal drilling is practised in the mid-horizontal zero plane, which is not a constant, both vertical and

transverse adjustments of the slide blocks (17, 18) are required. For this purpose the anterior and posterior transverse guides (15, 16), which carry the slide blocks of the longitudinal drill guides, terminate at both ends in joints (21, 21, 22, 22) which slide vertically on the anterior and posterior pairs of legs (Pl. X, 65, 65, 66, 66) of the cage, and they can be raised or lowered and fixed with screws at any height on the legs which are graduated with millimeter scales. By this arrangement the anterior and posterior drill guides are brought to the same level and accurately opposed, first in the median sagittal plane and then at corresponding points 10 mm. to right and left of it.

Drills.—The drills, employed in the manner described, should be tempered and of about No. 14 standard wire gauge, 1.8 mm. in diameter; this is the smallest size which possesses sufficient rigidity for drilling a cranium as large as that of a rhesus monkey and would not be rigid enough for a larger head. Different forms of cutting points have been tried, the awl point, triangular in section, appearing to be the most satisfactory, although, theoretically, it is not a good form of drill, as it has no clearance or cutting edge; nevertheless, it penetrates the skull and its point is less easily deflected by an oblique surface of bone or membrane than more orthodox forms. When any form of drill engages such an oblique surface it should be run with light pressure and as rapidly as possible; a motor should be used if it is available, but an ordinary hand drill will generally give satisfactory results.

Preparation of Microscopic Sections.—It has been mentioned that the drill is chiefly used for identifying the zero planes in chart sections, and that anyone may have occasion to use it for that purpose. Drill marks are sometimes useful, especially for beginners, to assist in the localization of lesions and the identification of structures in microscopic sections. Most of us have wasted time and trouble in acquiring this accomplishment under difficulties owing to the capricious selection of planes of section and it is to be hoped that the adoption of constant planes in the charts will help to abolish such a gratuitous infliction. The following procedure is recommended for the topographical purposes referred to:

As a preliminary, the brain must be injected. A cannula is introduced into the thoracic aorta, the right side of the heart opened and a warm solution of 5 per cent formalin and 2 per cent potassium bichromate injected from a bottle raised from 1 to 2 meters.

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It is advisable to introduce ear cones before the injection, as with formalin the meatus becomes rigid. The head is then adjusted in the frame and the drill is applied in the cage in the zero plane perpendicular to that in which the sections are to be made, so that the punctures will appear as points in every section. This zero plane, and the one at right-angles to it, will be represented in every section by crossed lines. One of the punctures should be at the point of intersection and the two others 10 mm. on each side of it. If these punctures are visible in a section, by applying a glass plate with crossed lines ruled on it in such a way that the intersection coincides with the middle puncture and the other two points with one of the lines, the distance of any point in the section from the two zero planes represented by these lines can be estimated. To measure the objective point from the third zero plane, the sections must be made in accordance with that object. To effect this, in addition to drilling perpendicular to the plane of section, the zero plane parallel to the sections must be marked by two drill punctures, on each side which penetrate far enough to be seen on the surface of the brain, so that it can be cut accurately in this plane. After it has been hardened and the bone removed, the brain is divided in the zero plane marked by the punctures. Each half is then placed with the cut surface on a glass plate and the measurement of the dimension, from the zero plane to the surface, taken with a depth gauge. In cutting the sections, the division into lamellæ must be observed and the sections numbered accordingly. This object may be carried out in various ways. In the first place, the brain may be embedded in gelatine, 15 per cent, and glycerine, 5 per cent, and frozen, or it may be embedded and cut in celloidin; but in either case it must be divided into the correct number of lamellæ for the dimension by a proportional scale, after deducting the average thickness of the skull at that part of the cranium. One method is to fit the proportional scale to the microtome, an index recording the the movement of the knife (or the object) on the spirals of the scale; the spring may be included in a circuit and a brush contact with the spirals arranged to indicate by a signal each lamella as it is cut. Or, if preferred, the brain may be cut in the macrotome into proportional slices approximately 2 mm. thick. Here an index and proportional scale register the movement of the plate of the macrotome, each slice representing two lamellæ. When the sections are mounted, the slides are marked with the number of the lamella and section, which gives

one of the measurements required for localizing any given point in the section. The other two are found approximately, and sufficiently accurately for practical purposes, by applying a glass plate, ruled in square millimeters to the slide, guided by the punctures which have been made in the section.

It may be observed that two punctures, one at the point of intersection and one 10 mm. from it on one of the zero lines, are sufficient for the correct application of the ruled glass plate, but three punctures are preferable, because one is sometimes missing, as, for instance, when it falls in a space between the hemispheres. But two out of three are generally visible and, as they are 10 mm. apart, any two suffice for the application of the plate and the restoration of the missing puncture.

Gauging.—The slide blocks, perforated with cylindrical slots for the drill guides and provided with a graduated adjustment on the traversing guides of the cage, are equally well adapted for measurement of the cranium with the needle gauge. The pattern of this gauge (Pl. XXXIV, 26), used with the drilling frame, is a cylindrical tube, 6 mm. in diameter, which fits the slots in the slide blocks. The slots are guides for the gauge and their outer margins are the indices which read the graduations engraved upon its surface. A cylindrical rod, carrying a needle at one end and a milled head (28) at the other, fits the tube of the gauge. The needle projects from one end and, at the other, a screw thread extends a short distance from the milled head, engaging a corresponding screw at the end of the tube so that by rotating the head of the rod, the needle can be projected from the tube or withdrawn. A perforated cap (27) tapering to a blunt point fits over the needle and is screwed on to the tube like the point of a pencil-case; when screwed home, the point of the cap is a constant from which the gauge is graduated. The needle can be projected through the cap or made exactly flush with it, in which case the measurements on the scale from the point of the needle and the cap are identical and the point of the cap or, when it is removed, the sharp point of the needle can be used indifferently for gauging. The tube is graduated with a millimeter scale, reckoned from a zero near the distal end towards the point of the needle or cap. As in the cage of the rectilinear machine, all the diameters, from any external surface or bounding plane of the measuring cage, to the zero plane parallel to it, are identical, vertically, transversely and longitudinally, and

when the gauge is projected through any slot from outside, till the zero mark is level with the index, *i. e.*, the outer margin of the slot, the point of the needle, or cap, is at the zero plane to which the gauge is perpendicular and this distance is always 85 mm. As the gauge is withdrawn the index shows the number of millimeters from the point of the needle to the zero plane, so, if the gauge is introduced till the point of the needle touches the cranium, after penetrating the soft tissues, the index shows the distance in millimeters of the surface of the bone at that point from the zero plane; this is one of the required dimensions which is thus determined quickly and accurately. It is advisable that measurements should always be made with the bare needle to the surface of the bone; the puncture of the skin in an anæsthetized animal is negligible and in the occipital region, especially in cats, the thickness of hair, skin and muscles is considerable and variable. With this instrument, the cranial measurements, from the zero planes to the surface of the bone, can be made rapidly at the same points, ensuring constant diameters, and the direction of the gauge must be perpendicular to the zero plane—important details.

Selection of Diameters.—The vertical and transverse diameters of the frontal zero plane in the rhesus and cat are not quite the maximum diameters of the cranium, which are usually about 10 mm. further forward, but the difference is slight, not more than 1 or 2 mm., as a rule; the position of the absolute maximum is not quite constant, and it is doubtful whether varying the diameter, in order to secure the maximum, would afford a better guide to proportional dimensions than measurements through constant points, which are always near the maximum. It is more convenient that all measurements should be made at the same points, and on the whole, it seems best to adhere to the zero plane.

The same considerations apply to the mid-horizontal zero plane, which is the level adopted for drilling and gauging. The basal plane is quite unsuitable for these purposes, as it is too low. The mid-horizontal zero plane is the best level and about the maximum in the longitudinal dimension; the maximum transverse diameter is rather higher, but the explanation just given applies here.

Longitudinal Diameter in Rhesus.—In the rhesus the anterior longitudinal measurement is taken from the frontal zero plane to the glabella, the lowest part of the frontal lobes available. This is about 10 mm. above the horizontal zero plane, but as the measurement is

between perpendiculars, parallel to the frontal plane, and the glabella is the most prominent point anteriorly, the exact level of this measurement is not material.

Frontal Sinus and Longitudinal Diameter in the Cat.—Owing to the large frontal sinus of the cat, the anterior limit of the brain cannot be defined from the outside in that animal. The anterior lobes are separated from the sinus by a thin plate of bone, about 1.5 mm. thick. This septum cannot be exposed without opening the sinus, which is therefore the only way to gauge the longitudinal diameter of the brain directly.

A puncture into the frontal sinus is a much simpler matter than one which penetrates the bone over the brain. It bleeds little, encounters no important structure immediately beneath it and can be expeditiously effected with one blade of the bone forceps. For animals not intended to survive the anæsthetic the direct measurement is the best. If a line connecting the posterior margins of the orbits is drawn transversely across the cranium, a puncture on it, through the frontal bone, about 5 mm. to one side of the sagittal zero plane, will give access to the anterior surface of the septum. The frontal lobes of the cat's brain are continued by the olfactory lobes in the form of a narrow prow or beak in the middle line. The bone which forms the septum is moulded over these structures and the most convenient point for measuring the anterior limit of the brain is at the angle where the root of this beak expands over the frontal lobes and which is about 4 mm. from the middle line. Having defined this, it may be measured from the front with the needle gauge or with a similar gauge (Pl. XXXIV, 34) which terminates in a small crossbar in place of the needle and which is intended either for this direct measurement or for that of the posterior margin of the orbit, which will be explained immediately. If the animal is to be kept alive, the contour of the septum can be felt with a probe through quite a small opening and the point described identified. In this case, after measurement, the sinus should be washed out with a 0.5 per cent solution of lysol and filled with boric acid. The septum is liable to some irregularity, and very rarely, and I think only in old animals, the whole sinus is filled with cancellous bone.

Although this procedure is not a serious addition to an operation, it would be more satisfactory to find a method of measuring the head without opening the sinus. It was pointed out in the atlas,

that in the cases examined the distance from the interaural line to the septum and the posterior margin of the orbit was the same on the average, *viz.*, 31 mm. The measurements were taken in preparations after removal of the skin, but it is possible to make it in a living animal, and the screw rods on the mask (Pl. II, 12, 13) are used for this purpose. They terminate in rounded ends which bifurcate to form a cleft, the bottom of which is indicated by a small stud on one of the forked ends. When the mask is in position, the screw rods can be elongated till the cleft engages the posterior margin of the orbit about its center, the rod is projected by the screw till the bottom of the cleft is in moderately firm contact with the posterior margin of the orbit, indicated by the stud, which is kept outside, and can be measured with a depth gauge from the front of the cage. The modified needle gauge just referred to is now used both for measuring the posterior margins of the orbits and the frontal septum from the front of the cage, but the rods can be employed for the purpose, so that it was not worth while to alter the figures which show them. Any method at present is only provisional and it will require more experience before we can decide whether the relations of the septum to the posterior margins of the orbits are sufficiently constant to be adopted as an established method of measurement. It is not possible, therefore, to speak positively, but apparently in animals that are near the average size, and this generally means young adults, the measurement is fairly constant. With age the bones grow more than the brain and the indication is less trustworthy—one of the advantages of selecting animals of average size.

The plan I adopt is to measure the posterior margin of the orbit by the method described; if it is not more than 32 nor less than 30 mm. from the frontal zero plane, I accept it as the measurement of the septum. It is not often less than 30 mm., but if it is more than 32 mm., for the second and every additional millimeter in the orbital measurement I only allow half a millimeter for the septum.

Whenever the measurement of the septum has been estimated in this way, if possible, after the animal has been killed, the head should be put in the instrument and the septum measured directly with the depth gauge and the results compared. If this rule is followed by several workers, before long we shall have sufficient data to settle this question.

It should be noted that the limits of this anterior frontal dimension are not of the same importance as the position of any of the zero planes from which direct measurements are made. It is only taken to estimate the relative size of that dimension compared with the standard, for the adjustment of the extensible scale. If there is an error, its extent depends on the distance of the objective point from the frontal zero plane. Thus an error of 1 mm. in the measurement of the dimension will amount to only a third of that distance if the objective structure is 10 mm. in front of the zero plane. But if the anterior part of the caudate nucleus were the objective, the error would be greater. In such a case it is advisable to select an animal of average size or to make a direct measurement of the septum with the pilot needle, or with the gauge, in the way described.

In the bones forming the posterior margin of the orbit in the carnivora there is a gap filled by fibro-cartilage; with the amount of pressure required, which is not great, it does not yield enough to affect the measurement.

CHAPTER VI

ILLUSTRATED DESCRIPTIONS OF INSTRUMENTS (Continued)

Indicators (Pls. XXV-XXVIII), Equatorial (Pls. XXIX, XXX), Adjustment of Scales, Quadrant Scales (Pl. XXVII)

The principal object of improvements in the mechanism of the stereotaxic instrument has been to secure as great a flexibility and range of movement of the operating needle as possible without sacrificing accuracy and rigidity. It is important that the operator should have a choice of routes from the surface to any point he wishes to reach in the brain; there may be tracts or other structures which it is desirable to avoid, and although the injury produced by the passage of the needle is comparatively slight, it should not be ignored, nor should the possibility of its contributing to the degeneration attributed to an intentional lesion be overlooked. Again, in stimulation experiments, owing to the tendency to "escape," valuable information for the correction of error may be acquired if the focal point is approached by different routes and any variations in the response are noted and compared. The difficulty of securing the above objects has been due to the necessity of combining qualities which are more or less antagonistic; the freer the movements the less easy it becomes to measure and record them. If we depend on scales attached to the instrument to direct the needle, its excursions must be rectilinear; at least I am not aware of any satisfactory method of registering inclined or universal movements by scales. Fortunately, there is no need of one, as it is improbable that any other method could serve the purpose better than the indicator, an instrument in which all the essential conditions presented by the head and the stereotaxic machine are exactly reproduced. An index point, representing the objective, is adjusted with identical relations to three index planes which correspond to the zero planes of the cranium. Four pillars are fixed to the floor of the indicator in such a position that slots, like those of the head-vice, with which they are provided, have similar relations with the index planes and consequently with the index point. Any mechanism, for directing the operating needle, which fits into the

slots of the head-vice, can be applied to the corresponding slots of the indicator and must have identical relations to the zero planes, and any points at the same distance from them, in both instruments. A single operating mechanism can be employed and transferred from the indicator to the head-vice; or, duplicate instruments may be used with corresponding scales in which the movements are directed by sight in the one applied to the indicator and copied in the other; or finally, a needle may be directed in the indicator from a frame, which, without being a duplicate of the operating mechanism, reproduces its essential parts and movements and records the latter with corresponding scales. The operating mechanism in the rectilinear instrument consists of a cage and traversing stage carrying a needle, the cage being fitted to the slots of the head-vice and the needle directed by scales to the objective point. This mechanism can also be applied to the slots of the indicator, if required for inclined movements of the needle which cannot be directed by its scales. Another form of operating mechanism, which affords the needle universal movement, is the equatorial; it fits the corresponding slots in the head-vice, and the indicator by which all its movements are directed. Thus, if either the cage or the equatorial is applied to the slots of the indicator, the needle can be manipulated in view, by any available movement, in any direction, from various positions, till it reaches the index point, and if the mechanism is then transferred to the head-vice, the needle will be at the corresponding point in relation to the zero planes of the cranium; *i. e.*, at the objective point. It is a simple mechanical procedure requiring no anatomical knowledge and, with one exception, no alteration in the adjustment of any part of the mechanism, nor even the use of the scales. The exception will be apparent; to reach the objective point in the brain the needle must penetrate the skull, which is trephined for the purpose. The operating mechanism cannot, therefore, be applied to the head-vice with the needle fully projected; its extension must be adjustable and regulated by a scale. When the needle has reached the index point in the indicator the position on its scale is noted; it is retracted sufficiently to permit of the application of the cage or equatorial to the head and then projected till it touches the skull. This point is marked. The cage can be removed while the skull is trephined, then replaced, and the needle racked through the brain to the figure noted on the scale, when it will have reached the objective point.

This method of using a single operating instrument, either cage or equatorial, and transferring it from the indicator to the head has the advantage of simplicity. No scales are necessary except the one which records the projection of the needle, and even accuracy of the instrument itself is not of vital importance; so long as the slots have identical relations to the index and objective points in both instruments, if the needle is brought to any selected point in one instrument, it must be in the corresponding position in the other. For the majority of experiments, therefore, this method will probably be preferred, but a larger field of operative procedure is opened by employing duplicate instruments, one of which is applied to the indicator, and the other to the head; every movement, regulated by corresponding scales, is directed by sight in the indicator and copied in the duplicate. Here accuracy in every detail of both instruments is indispensable, as well as care to observe that the readings of all corresponding scales are identical. It may be questioned whether any probable advantages can compensate for the obvious defects of this method, the sacrifice of simplicity and a considerable increase of trouble and expense. There are some very decided advantages, but, perhaps fortunately, they are associated more with probable developments of the methods in the future than with their immediate application. But, even now, with the forms of cutting needles which are described (Chapter IV, Pl. XVII) and without counting on others which may be designed, there are planned operations for isolating centers, or nuclei, or tracts of considerable size, which may be of great value. It would be very difficult to carry these out with a single instrument, but they may be accomplished in consecutive steps, directed by sight in one instrument, and copied in the other. It will, I believe, be practicable, by substituting fine steel bars for silk threads in the gratings, to reconstruct a reproduction of various structures of the brain upon the floor of the indicator; instead of one index point there may be many, connected by elastic threads representing tracts, or blood vessels, and models of nuclei may be introduced. The reconstructions would be permanent, but with movable needles carried by the steel gratings and the use of elastic threads, the whole reconstruction could be automatically adjusted in three dimensions for variations in size, and operations of some extent performed with precision. It is upon these lines that we may look for the application of the methods of surgery, but such developments

are more or less speculative and, for the present, we may be content with the simplicity and convenience of a single instrument or, at any rate, resort to duplicates only for certain special investigations.

There is an application of this method, however, available at the present stage with either a single or duplicate instrument which deserves mention. It consists of the utilization of hardened brains as models in which planned operations are carried on in one instrument and copied by means of corresponding scales, etc., on the brain of another animal of the same species, fixed in an identical machine; or, the operation may be carried out by sight on the model and every movement noted on the scales or recorded. The head of a living animal can then be fixed in the same machine and every detail of the operation repeated. Brains hardened in formalin and bichromate shrink very little and if the brain selected for the model is very nearly the same size as that of the animal operated on, the proportions of structure or nuclei upon which the operation is performed will generally be very similar. The model must be marked before the bone is removed in the manner described in Chapter V, so that, after it is hardened, the zero planes can be readily identified. It is fixed in a holder supported on a universal joint on a pillar which can be screwed into the plate of the indicator; the model can then be adjusted and fixed so that its zero planes correspond with the white zero lines of the gratings and any desired operations can be carried out with equatorial and the cutting needles described. Then either repeated on a head in another instrument with another equatorial, or, the recorded movements of the needles can be repeated with the same equatorial and needles, transferred from the indicator to the instrument attached to the head of the selected animal. In both cases the needle is directed by the scales, which are adjusted to repeat the procedure in the operation on the model.

At the present time, it seems probable that we may obtain important information relating to the anatomical connections and the functions of large nuclei, and other structures, if their communications can be cut and they can be more or less completely isolated without mutilation. This may be effected by employing the finest hypodermic needles from which steel wires can be projected for cutting purposes.

It is a practicable operation with the instruments now available and is not a merely speculative suggestion.

In the foregoing description of the principles of the indicator, I have assumed that the index point is correctly defined, by constant units of measurement, from three index planes which correspond to the zero planes of the charts and cranium, and in the simplest form of indicator the measurements are in millimeters, as they are in the rectilinear machine. But, as has been explained, in the charts the units are coordinates proportional to the dimensions of the heads selected for section; in order, therefore, that the index point should coincide with the objective in the head chosen for operation some means must be adopted to correct the measurements for variations of size. If millimeter scales are used, they must be corrected by calculation or tables, but a mechanical method of correction is much more convenient and has been adopted in the indicators which have been constructed and are shown in the illustrations (Pls. XXV, XXVI, XXVII). Millimeter scales, however, are cheaper and their employment on economical grounds may deserve consideration, especially if the corrections are made with a mechanical calculator which saves a certain amount of time and trouble.

It has been explained that, owing to the difference in cost, it was desirable to give descriptions of two patterns of the operating mechanism, the simpler form, with rectilinear movements and inclination of the needle in one plane, in each position, and the more elaborate equatorial, with a wider range of movements which are practically universal. Similar reasons require a corresponding variation in the patterns of indicator which may be selected, the choice of which may depend on questions of cost, the pattern of stereotaxic instrument employed, and the work for which it is required. The **three-dimensioned indicator**, with mechanical correction for variation of size, effected by adjustable gratings, is the best, but it is expensive; it is designed for use with the equatorial, with which the needle can be directed in any position and at any angle, but it serves equally well for directing the inclined movement in the rectilinear machine and so fulfils all purposes. If a cheap pattern is required, it is probably most satisfactory to use a modified form of the same instrument, in which a card ruled with square millimeters is substituted for the adjustable gratings, the corrections for size in three dimensions being made by tables or calculation. But, with the rectilinear instrument, as the inclination of the needle is possible only in one plane, a **two-dimensioned indicator** is sufficient. It represents all the movements

of the needle in one plane and can be constructed with a ruled card and millimeter scales, which require correction; or, as described with the three-dimensioned pattern, corrections can be effected mechanically with a reticulated screen formed by crossed adjustable gratings. I have not had occasion to use either of the ruled card patterns, but their construction will be explained. In the general description of instruments in Chapter III a short account of the indicator is given which has, I hope, conveyed some idea of its principles of construction, which will now be described with the help of Plates XXV to XXVIII in more detail. The principle of the two- and three-dimensioned indicators is the same, but in the former two gratings only are employed, combined to form a reticulated screen, and the movements and inclination of the needle are all in one plane; whereas, in the latter, three gratings are used to define the index point and the needle can be directed from any position and inclined in any plane. It is not necessary to add very much to the account already given of the method of substituting a ruled card for the adjustable gratings in the three-dimensioned indicator; it has no advantage except on the score of expense and involves the correction of millimeter scales in three dimensions by calculation, which is objectionable. The following description will explain its construction:

The Three-Dimensioned Indicator with Ruled Card.—A horizontal oblong plate 90 x 70 mm., *i. e.,* rather larger than a horizontal lamella in the rhesus, is mounted on a vertical pillar, graduated in millimeters and raised or lowered in a socket by rack and pinion. Cards ruled with square millimeters can be fixed to the plate, each card being marked with a crossed longitudinal and transverse line, representing the sagittal and frontal zero lines of a horizontal lamella in the charts. These zero lines must correspond with marks on the plate, so that the position is constant. On the stand that carries the pillar and plate there are four corner columns, the upper surfaces of which are slotted to receive the bolts on the feet of the cage or equatorial; the slots have the same relations to the crossed lines on the card as those in the horizontal frame or head-vice (Pl. V) have to the interaural and frontal sagittal zero planes of the cranium. The columns are all the same height, the table is brought to the same level and at this point the scale on the pillar is marked zero; this, the level of the surface of the columns and slots, is the basal zero plane and, the point being marked, the table can be raised or lowered

any required number of millimeters above or below it. Any square millimeter on the card, of given distance from the zero lines, can be identified and marked and, the plate being adjusted to the given height in relation to the basal zero, the marked square represents a cubic millimeter, the required distance in three dimensions from three index zero planes, which have the same relations to the slots of the corner columns of the indicator as the zero planes of the cranium to the slots of the head-vice. If the cage, or equatorial, with the needle mounted is applied to the slots of the indicator or head-vice and the needle is fixed in any position, it must have the same relation to the three zero planes in both instruments and consequently the same relation to any point at the same distance from them. We can, therefore, use either form of operating mechanism, *i. e.,* cage or equatorial, and fit it on the slots of the indicator, manœuver the needle from any available position, by any practicable movement, till the point touches the marked square on the card, the position is noted on the scale of the needle and all other movable parts fixed. The needle can now be retracted as far as may be convenient, the cage or equatorial transferred to the frame on the head, the skull trephined and the needle finally racked in to the figure noted on its scale, when it will arrive at the objective point in the brain. The measurements will have been in millimeters and assume a standard head; for variations in the size of a selected head in any of its three dimensions corrections must be made, with a mechanical calculator if preferred, both on the ruled card and the scale of the pillar.

The **three-dimensioned indicator** illustrated in the accompanying plates (XXVII, XXVIII) is constructed on the same principles as that just described, with the exception that the position of the index point is determined by three adjustable gratings instead of the millimeter scales of the card and pillar; the gratings are corrected for variations in the size of any selected head, in three dimensions, and as the position of the index point is determined by these gratings, it is varied in the same proportions and the measurements require no further correction.

Three adjustable gratings represent the three zero planes in longitudinal, transverse and vertical dimensions, and the index point is identified and measured from them by two needles, carried upon movable bars, so that they can be made to correspond with any divi-

sions of the gratings. When they are adjusted, the point of intersection of the two needles is the given number of divisions or coordinates from the zeros of the gratings in three planes.

The longitudinal and transverse dimensions are represented and measured by two horizontal gratings, closely applied to one another at right-angles to form a single reticulated screen (Pl. XXVII, 4, 8, 12). The gratings are formed of silk threads, stretched between pegs on opposite pairs of sway bars (5, 9, 13) which can be adjusted at any angle within the limits of their movements. By graduated quadrants (6, 10, 14) and screws (7, 11, 15) they can be fixed in any position and the spaces between the threads regulated and measured. On one of each pair of sway bars a stretcher is applied to regulate the tension of the threads, which are divided by contrast colors into groups of five, so that they can be counted quickly. It will be seen that white threads pass between the centers of the pivots of opposite pairs of sway bars; these threads are not moved by inclining the bars and they represent the zeros from which measurements are made; in the horizontal screen, two of these threads represent the interaural and median sagittal zero lines. Two white threads on each side of the median sagittal line define the transverse dimensions of the standard cranium of the cat and rhesus monkey and when the quadrant scales are set at 40°, so that the divisions of the grating measure millimeters, these lines represent the transverse dimensions in standard animals. In the transverse gratings, similar white threads represent corresponding anterior and posterior measurements in the same animals.

Adjustment of Gratings.—The transverse grating is composed of two pairs of sway bars and consists of a prefrontal and postfrontal portion, each of which can be adjusted independently. This is necessary, because variations in these dimensions do not always correspond in the same cranium; the prefrontal dimension may be greater than the standard and the postfrontal less, or vice versa. When the quadrant scales are set at 40° the divisions measure millimeters in all gratings and each degree on the quadrant scales is equivalent to one-fortieth of a millimeter in every division of the gratings; consequently, the effect on a whole dimension, represented by a given number of threads, produced by moving the sway-bars one degree on the quadrant scale, depends on the number of divisions in the dimension. A dimension of 40 divisions is varied 1 mm. by a movement of one degree, one of

20 divisions, half a millimeter, and so on; and if it is desired to vary a dimension a given number of millimeters, the proportion of that number of millimeters to degrees of the quadrant will be the same as the number of divisions of the dimension to 40. If the dimension has 20 divisions then 20 : 40 :: number of millimeters : number of quadrant degrees. The gratings can be adjusted most quickly with the quadrant scales, but they can also be set easily by direct measurement. If a bevelled millimeter scale, or ruled glass plate, is laid upon a grating, its zero corresponding with a white zero thread, when the scale is set at 40° it will be seen that a dimension bounded by two white threads corresponds to the standard. It is easy to increase or diminish it by one or more millimeters by moving the sway-bars. The longitudinal and transverse dimensions are gauged therefore by a reticulated horizontal screen, and the vertical dimension is measured by a vertical screen something like a lawn-tennis net (Pl. XXVIII, 16). It is a single or gridiron grating and has three white threads, the lower of which corresponds to the basal zero plane and the upper to the vertical dimensions in the standard cat and rhesus. It is provided with a graduated quadrant (Pl. XXVII, 33) and can be adjusted and fixed by means of this, or by direct measurement, in the manner described.

In practice, when the several dimensions of a selected head have been ascertained with the needle gauge, the divisions of the gratings, which correspond to the number of millimeters in the corresponding dimensions of the standard, are made to measure the same as they do in the selected head, either by the quadrant scales or direct measurement. In the former case, the grating representing the dimension is set at millimeters by bringing the index of its quadrant scale to 40°; the dimension of the selected head must measure the same as the standard, or more, or less. If the same, the scale being at 40° is correct, if more, or less, the needle gauge gives the amount of the variation in millimeters. The equivalent of the millimeters in degrees of the quadrant scale can be stated as a simple proportion sum, as already explained, and this can be read off on a mechanical calculator if desired. The number of degrees, so determined, must be added to or deducted from 40°, at which the index has been set, and which is reckoned as zero on the quadrant scale. The method of applying direct measurement has been explained.

Having set the gratings, the next step is to define the index point with the two needles referred to.

The **index point** is the representation, in the indicator, of the objective point in the brain; it is identified in a chart and its distance from the three zero planes determined; the same distance is measured in the gratings, by counting the divisions from the zero lines. In the reticulated horizontal screen, it is identified as a mesh, the required distance from the zero lines representing the interaural and median sagittal lines, and in the vertical screen, the given number of horizontal divisions above or below the white thread representing the basal zero. The actual position of the index point is defined by two index needles. A horizontal radius bar (Pl. XXVII, 23) is fitted in a rotatory joint (20) from which it can be projected by rack and pinion (22), the joint is pivoted (20) on the plate (1) which carries the gratings, outside them, so as not to interfere with their movement; by rotation on the pivot and projection from the joint, the distal end of the radius bar can be made to travel all over the horizontal screen, which it nearly touches, by a series of concentric curves and so brought to any mesh of the screen. At the end of the bar there is a **V**-shaped slot carrying a vertical index needle (24) which can be raised or lowered and fixed with a screw (25). This needle can therefore be made to coincide exactly with the measured mesh of the screen and represents the position of the index point in two dimensions, it is the required distance from the interaural and median sagittal zero lines. By a similar arrangement, the position of the index point in the vertical dimension is defined by a horizontal index needle (Pl. XXVIII, 29). A vertical radius bar (27), like the one described, is moved by rack and pinion in a rotatory joint (30) pivoted above the vertical screen (16). The bar can be moved all over the vertical screen, with which it is almost in contact, and brought to any of its horizontal divisions; a slot (28) at the end of the bar (27) carries a horizontal index needle (29) which can be projected in its axis and fixed with a screw. By the rotation and projection of the radius bar, the horizontal index needle is brought to any point in any required horizontal division of the vertical grating and adjusted so that its point reaches the vertical index needle at this level; the vertical index needle can be raised or lowered till their points meet and this is the position of the index point (Pl. XXVIII) determined by the corrected gratings in three dimensions. The definition of the index point by

bringing the points of the vertical and horizontal index needles into contact, as described, is the simplest in principle, but in practice such adjustment of the points of two needles, at right-angles to one another, requires some manipulation. The following plan is more convenient: The vertical index needle (Pl. XXVIII, 24) is replaced by a small square rod, which can be raised and lowered in the V-slot at the end of the radius bar (23), but is not liable to rotate; a short horizontal arm, projecting from this rod, terminates in a minute horizontal cross and the index point projects upwards for half a millimeter from the point of intersection of the arms of the cross. When the horizontal index needle is in contact with the upper surface of any of the arms, the index point reaches to half the thickness of this needle. The cross is brought over a given mesh in the horizontal screen; the horizontal index needle, adjusted to the correct height by the vertical screen, is brought over the cross, which is raised till an arm touches the horizontal needle, when it is fixed. The apex of the index point is then level with the center of the horizontal needle and, at the same time, directly over the given mesh, and therefore the required distance from the three zero planes; the operating needle is directed to this point.

In the three-dimensioned indicator represented in the illustrations, the horizontal radius bar is very close to the horizontal grating and the vertical movement of the cross, with the corresponding excursion of the rod which carries it in the slot of the radius bar, involves pushing the lower end of the rod through the meshes of the horizontal grating, which tends to slacken the threads. To obviate this it is better to have two crosses, one above the other, either of which can be selected, and if the upper or under surfaces of the crosses are alike, either will serve to represent the index point; as the rod can be reversed, the operator has the choice of eight index points at different levels to select from and one of them can be brought to the required height with very little adjustment. A sketch of this device is given in Plate XXVIII. A.

A square rod (1) fits the slot in the horizontal radius bar (23) and can be raised or lowered and fixed with a screw; it has two horizontal arms (2 and 3) one above the other in the same vertical line; each of them bifurcates and terminates in two small rings which hold the central pivot of the cross between them allowing it to rotate in the horizontal plane. The cross is a miniature wheel with four spokes,

the nave is a little tube, about 2 mm. in diameter and 3 mm. long; the two ends are the same distance from the spokes and either of them serves for the index point (4, 4′, 5′.) Being in the same vertical line, a needle (8) can be passed through both to the marked mesh of the horizontal grating, which it can penetrate without interfering materially with the threads, and ensures the correct position of all the index points in two dimensions, longitudinal and transverse. The arms of the cross, corresponding with the longitudinal and transverse threads of the grating, help to bring the needle (8) directly over the marked mesh. If neither of the horizontal arms (2, 3) is near enough to the level of the index point on the vertical grating, the rod (1) can be reversed and the lower ends of the tubes or naves of the wheels 4′, 5′ will be uppermost and one of them can be taken for the index point. It must be raised by elevating the rod (1) till an arm of the cross is in contact with the under surface of the horizontal index needle (29) which has been brought directly over it. The index point, *i. e.*, the upper end of the tube, will then be level with the center of the horizontal index needle, and the operating needle can be directed to this point as previously described.

The **vertical grating** is attached to the plate of the indicator with two screws (17) and is removed as soon as the index point has been defined, to allow free play to the operating needle, which can be used with either cage or equatorial. The only difference between this indicator and that with a ruled card previously described is in the method of defining the index point by adjustable gratings and making the necessary correction for variations in size once for all. The application of the cage, or equatorial carrying the operating needle, is identical in both forms. This has been described and the advantages of employing single or duplicate instruments have been explained.

Two-Dimensioned Indicator.—The first indicator constructed was the two-dimensioned pattern illustrated in Plates XXV, XXVI. It was designed and employed for directing the inclination of the needle in one plane in the rectilinear machine. As the three-dimensioned pattern just described serves the same purpose, it is not necessary to procure both instruments, but the latter is more expensive and the question may occur to anyone who proposes to work with the rectilinear machine whether the two-dimensioned form, which is cheaper, would not suffice for his requirements. No doubt it might, but there is more than one alternative; both forms of indicator can be made

with adjustable gratings which, when once set, obviate any further corrections for size, or with ruled cards, which are a good deal cheaper, but with which corrections for size must be made by calculation, or with tables. This is objectionable, but it is rather a question of individual taste and opinion and it is therefore advisable to give a description of the two-dimensioned instrument to help the reader to judge for himself. The principle of the two-dimensioned indicator has been explained in Chapter III, and it is only necessary to recapitulate the essential points very briefly. In the rectilinear machine, when the operating needle has been brought, by one movement of the stage, to the edge of a lamella which contains the objective point and is in the same plane as the inclination of the needle, the lamella may be compared to the page of a book, the objective point to a letter on that page and the needle is at the edge of the page with its axis parallel to it. The needle can be fixed at any angle within a limit of 25° and it can be directed to the objective or letter by sight, by the two movements which are available, namely, (1) the second movement of the stage, parallel to the page or lamella, and (2) the projection of the needle in its axis. Of course, it cannot be so directed if the objective is not visible, when, for instance, it is a point in a lamella which is only a hypothetical slice of the cranium fixed in the machine. But, if we remove the head and substitute a scale photograph of the lamella, or a card ruled with square millimeters and with crossed lines representing the zero lines of the chart, and fix this in the machine, in the position of the lamella, so that their zero lines would coincide, we can then direct the needle, by the movements defined, to any point or marked square of given distance from the zero lines, note the position of the needle on its scales, retract it, then replace the head in the machine, trephine and rack the needle to the figures noted on its scales, when it will have reached the corresponding point in the lamella in the brain. To avoid the removal of the head, we may fix the card in a duplicate instrument, direct the needle by sight in the same way and copy the movements by corresponding scales in the operating machine. Finally, since all those movements are in one plane in the operating machine, they can be accurately reproduced if the card is fixed in a square frame; one side represents one of the guides of the stage and carries a slide block to which is pivoted an extensible needle, or finder, with a quadrant and scale, by which the finder can be set at a given angle. By the movement of the slide block on the guide,

and the projection of the finder in its sheath, which correspond to the two available movements in the operating machine, the finder is directed, by sight, to the marked square. The dimensions of all these structures are the same as their counterparts in the machine and they have identical scales; it is, therefore, easy to copy them and bring the operating needle to a point, at the same distance from the zero lines of the lamella as the marked square is from the crossed lines of the card. In the operating mechanism of the rectilinear machine by applying the stage to different surfaces of the cage, by a single movement, the needle can be brought to the edge of a frontal, sagittal, or horizontal lamella. In lamellæ of different planes the crossed lines represent different zero lines. By varying the position, or point of view, the card in the indicator can be made to represent lamellæ in different planes, the crossed lines representing different zero planes accordingly. The adjustment required to make the indicator correspond with the operating instrument in different planes will be soon recognized and is facilitated by assuming a section of the machine in the plane of the lamella; the correspondence of the counterparts in the indicator and the plane section of the machine will then be obvious. This is the two-dimensioned indicator in its simplest and cheapest form. It fulfils all the requirements for heads of standard size, but in practice these are rarely found and the square millimeters of the card must be corrected for variations of size in the corresponding dimensions of the selected head, by calculation or by substituting an adjustable reticulated screen for the card. The arrangement of such a screen has been sufficiently explained and is shown in Plate XXV; the frame carrying the needle is applied over it (Pl. XXVI).

The details of the instrument illustrated in the plates require some further explanation. In the **gratings** shown in the plates of the three-dimensioned indicator (Pl. XXVII), which would also be used for the two-dimensioned form in future, the divisions are approximately millimeters. They can be set to measure millimeters, or more, or less, but it was difficult to get gratings made as small as this at first, so it was necessary to double the size of everything in the indicator, every nominal millimeter measuring two. All parts were enlarged in the same proportion and therefore this did not affect the result any more than reading the scale of the indicator through a magnifying glass, but it made the instruments cumbersome. This

was obviated in another way. The crossed lines divide every lamella into four quadrants and the objective point must be in one of them. It is, therefore, sufficient if that quadrant only which contains the objective is represented. This plan was adopted; the quadrant is bounded by two zero lines and the index point is defined by counting the required number of divisions of the grating, or coordinates, from those lines. It is necessary that the indicator should be capable of representing any quadrant in a lamella, in any of the three planes. This is provided for by using three movable bars, called zero bars, two of which can be made to coincide with two threads of the corrected gratings and form the sides of any quadrant that is required; the index point being identified by counting the divisions from these zero bars, two of which represent the zero lines bounding any quadrant, in any lamella. It has been mentioned that in the cage, as now constructed, all the diameters from any surface to the zero plane parallel to it are equal; hence the distance from the pivot of the needle to the zero plane perpendicular to it is a constant, measuring 70 millimeters in the machine. In the indicator, the zero bar perpendicular to the finder is, therefore, a constant and is fixed at 70 millimeters from the pivot, or in this particular instrument at double that distance, *i. e.*, 140 millimeters; it is always one of the two zero bars forming the quadrant and is called the first zero bar (Pl. XXVI, 12). When first constructed, the diameters of the cage in longitudinal, vertical, and transverse dimensions were different and the first zero bar had to be varied in accordance with the dimension represented, the letters *L. T. V.* for longitudinal, transverse and vertical were for this purpose, but are no longer required. The first zero bar is brought to coincide with a thread of the grating by sliding the whole frame on plates shown in the illustration (Pl. XXVI, 9) the distance from the finder (28), which moves with the frame, to the zero bar being therefore maintained. The required quadrant is completed by using one of the other two zero bars (13, 14), the one selected depending on the position of the quadrant to be represented; only one bar is required and, therefore, whichever is selected, it is called the second zero bar; as they cannot be distinguished as right and left, for these positions may be reversed, they are identified as second zero bars *A* and *B*. One of these bars is made to coincide with a thread at right-angles to the first zero bar and the quadrant is complete. The bars must coincide with threads, because the index point is identi-

fied by counting the number of divisions of the grating from these bars. The second zero bars carry scales (25, 26) which move with them and are read by separate indices (27) fixed to the slide block (23) which carries the finder (28). The movement of the finder on its guide (24) is registered by this index and scale and shows the distance of the finder from the zero bar and therefore from the zero line it represents. The finder can be extended in a sheath, and a scale and index (21) show the length projected from pivot to point.

In using this indicator the procedure is as follows: The indicator having been placed in a position to represent the quadrant in which the objective point is localized (as previously mentioned, this is facilitated by assuming a section of the machine in the plane of the selected lamella and comparing the section with the indicator), the next thing is to set the gratings to correspond with the measurement of the two dimensions of the selected head. The first zero bar (12) is then made to coincide with a thread of the grating, it does not matter which, and fixed. It will be seen whether second zero bar *A* or *B* is required to complete the quadrant, this, of course, depending on the quadrant to be represented; whichever is chosen, it is made to coincide with a thread at right-angles to the first zero bar and the quadrant is completed. The index point is defined by counting the number of divisions of the gratings from the two zero bars; the mesh so identified should be marked with a pin or a small roll of paper. The finder (28) is now set at the required angle by its quadrant scale (15) and fixed, then the point (22) of the finder is brought to the marked mesh of the screen by two movements (1) of the slide block on its guide, corresponding to a movement of the stage in the machine, and (2) the projection of the finder in its sheath. The inclination of the finder, shown on its quadrant scale, has been determined; the index on the slide block reads the scale of the second zero bar and records the distance of the finder from the bar and therefore from the zero plane it represents, while a scale and index on the finder and its sheath show the distance from the point of the former to the pivot, by which it is attached to the slide block. The operating needle in the machine is set at the same angle; it is moved the same distance from the zero point on the guide of the stage parallel to one dimension of the lamella, which corresponds to the guide on which the slide block travels in the indicator; and finally, the needle is projected from its sheath till the point is the same number of

millimeters from the pivot as in the finder, when it will have arrived at the objective point in the brain.

In future, a two-dimensioned indicator on these principles will not be constructed on exactly the lines described and shown in the plates. The difficulty of making gratings with millimeter divisions has now been surmounted; hence, a reticular screen, formed of two such gratings, will be employed to represent the whole lamella instead of one quadrant; the crossed lines will be represented by the white threads extending between the pivots of opposed pairs of sway bars. The indicator, therefore, will be like the first one described with a ruled card, the only difference between the screen and the ruled card being that one is adjustable and the other is not; there will be no zero bars, the frame will not require to slide and the movement of the slide block will be recorded by a scale on the guide, exactly as it is in the stage of the machine. This will be a simpler instrument than the one described and illustrated and it may seem superfluous to have devoted so much space to an indicator which will be superseded. But I think it is desirable, if possible, to describe instruments which have been tried and point out their defects and suggested improvements, rather than to furnish accounts or drawings of designs which have not been tested; for however satisfactory these may appear, it is impossible to be certain that they are so, till they have been tried.

The Equatorial (Pls. XXIX, XXX)

The equatorial is a mechanism for carrying and directing the operating needle. In construction it is similar in principle to the astronomical instrument and, within the available limits, it affords universal movement to the needle and can be substituted for the cage and stage of the rectilinear machine. It is supported on four feet with bolts precisely similar to those of the cage and which fit the slots of either the head-vice or indicator, and the needle, in any position, has the same relation to the three zero planes, and to points at the same distance from them, in both instruments. Therefore, if the needle is brought to the index point in the indicator and the equatorial, after fixing all movable parts, is transferred to the head-vice, the needle will be at the objective point in the head; or, if duplicate equatorials with corresponding scales are employed and the needle is directed by sight to any point of measured distance from the zero planes in the indica-

tor, by making identical movements, guided by the scales in the duplicate instrument, the needle will reach the corresponding point in the head though the point is not visible. As already explained, the first method has the advantage of simplicity; the second, of enabling the operator to perform operations of some complexity.

The instrument consists essentially of a turntable formed by two flat, concentric, horizontal rings; the outer (Pl. XXIX, 36) fitting and rotating freely round the inner (35) and surrounding the head at the level of the basal zero plane. The inner ring has four bolts (37, 38) on its under surface which fit into the slots of either the indicator or the head-vice and can be locked. The rings are graduated and all movements of every part of the instrument are checked by scales and fixed by clamping screws; but, except for verifying the position and making sure that it has not altered, the scales are not required unless duplicate instruments are employed. If it is intended to work with a single instrument, all the scales, except that which registers the projection of the needle, can be dispensed with. An arch (40), like the declination circle, passes across the outer ring to which it is perpendicular and to which it is attached by two terminal feet (42) which slide on rectilinear guides (41) fixed to the outer ring. The whole arch, therefore, has a rectilinear sliding movement, at right-angles to its own direction, by which it can be carried completely across the rings, and the head within them, in any position. A slide block (44) to carry the needle (98) is fitted to the arch and travels completely across it and can be fixed at any point with a clamping screw (45). The outer sheath (72) of the needle-holder is attached to the slide block by a quadrant (47), without which the projection movements of the needle in its sheaths would all be radial from the periphery of the arch towards its center. With the quadrant, which permits free inclination of the needle on both sides, its projection can be made rectilinear and parallel to any horizontal or vertical plane. The same needle-holder and needles are used as in the rectilinear instrument and have been fully described (Chapter IV). The excursion of both sliding and racked movement is registered by the same adjustable index attached to the outer sheath and a millimeter scale engraved on the left of the bed. There are thus five separate movements of the needle available, all of which are registered by millimeter scales and can be fixed at any point by screws. These movements are:

Movements.—1. Rotation of the outer round the inner ring; this rotation is complete and in either direction.

2. A rectilinear sliding movement of the arch on guides fixed to the outer ring, available in any position of the ring.

3. A movement of the carrier over the whole extent of the arch.

4. Inclination of the outer sheath of the needle on the carrier, regulated and measured by a quadrant.

5. Projection of the needle: (1) By sliding the inner in the outer sheath, and (2) by racking the bed in the inner sheath. Both movements are read by the same scale and index.

As the movements are independent and all of them can be employed separately or together in any combination, the needle can be moved from any position in any direction to any point.

Quadrant Scales (Pl. XXVI)

Adjustment of Grating.—The gratings of the indicator can be easily adjusted by direct measurement with a bevelled-edged millimeter scale or a ruled glass plate laid upon the threads. The zero on the scale is made to coincide with the zero thread of the grating and then the sway-bars are moved till the given number of divisions measure the required number of millimeters.

Graduation of Quadrant Scales.—The gratings are also provided with graduated quadrant scales by which they can be set more quickly. There are a few points in the use of these scales which require explanation. It would appear at first sight that the degrees of the quadrant scale should be equivalent to millimeters in the grating; for example, if the threads of the grating are 1 mm. apart, and a dimension, which is 30 mm. in the standard, is found to be 33 mm. in the selected head, we must add 3 mm. to the dimension, as it is represented in the grating, and make 30 divisions measure 33 mm. Apparently this ought to be effected by moving the sway-bars 3° on the quadrant scale, but this is not possible, for reasons which will be evident.

Inclination of the sway-bars affects all the spaces between the threads equally and, therefore, varies a dimension of 30 divisions twice as much as one of 15; hence, the value of a quadrant degree, for increasing or diminishing a given dimension, depends upon the number of its divisions. Now the gauge is graduated and the difference between corresponding dimensions of different heads is expressed in millimeters irrespective of the number of their divisions, and the millimeter

is a constant unit, independent of the size of the dimension, whereas the quadrant degree is proportional to it. To find the number of degrees equivalent to the millimeters, which represent the difference between the dimensions, we must multiply the millimeters by a number proportional to the number of divisions of the dimension, and the result may be called the coefficient for that dimension.

A convenient unit to select for a degree of the quadrant is one which varies every interval in the grating 1/40 of a millimeter. If the threads were in mathematical contact at zero on the quadrant scale and the sway bars were moved to 40° the threads would be 40/40 of a millimeter, *i. e.*, 1 mm. apart, and as millimeters are the units of the standard cranium, 40° is made the actual zero of the scale; in other words, when the quadrant scale is set at 40° the divisions of the grating represent millimeters. If we have to deal with a dimension which measures 40 mm. in the standard, for example, the vertical diameter in the rhesus, and set the quadrant of the vertical grating at 40°, the 40 spaces representing the dimension measure 40 mm. If the corresponding dimension in the selected head measures 41 mm., and we move the sway-bars to 41° on the quadrant, we add 1/40 of a millimeter to each division, *i. e.*, 1 mm. to the whole dimension, which now measures 41 mm. as it does in the selected head. But if our dimension had been 20 mm. in the standard, represented by 20 divisions of the grating with the scale at 40°, and the corresponding dimension measured 21 mm. in the selected head, then, if we moved the sway-bar to 41° on the quadrant, we should add 20/40 of a millimeter to the 20 threads and increase the whole dimension half a millimeter. So, to get the required increase of 1 mm. we must move the sway-bar 2° or, as we may express it, for a dimension of 40 mm. the coefficient is 1, for one of 20 mm. 2, for 30, 4/3, etc. A table of coefficients for any probable dimensions of the cranium of the cat and rhesus is appended, calculated to one place of decimals, which is sufficient for practical purposes. It is only necessary, with a given dimension, to find the difference between the standard and selected heads in millimeters, multiply this number by the coefficient for that dimension and the result is the number of degrees on the quadrant which must be added to or deducted from 40, as the selected head is greater or less than the standard. It may appear from this description that it would be quicker and simpler to measure the grating than to make the calculation required to set the scale; in practice it is not so, the

difference between corresponding dimensions is rarely more than 2 or 3 mm. and, with a table of coefficients, the correction is made at sight; even without the table the calculation is a very simple one. Since at 40° the divisions of the grating represent millimeters, for a given dimension a millimeter has the same proportion to a degree on the scale, as the number of divisions in the dimension has to 40. Stated as a proportion sum, the number of divisions in a dimension: 40:: number of mm.: number of degrees on the scale. If desired, this can be read off on the mechanical calculator (Chapter VII, Pl. XXXVI). If 40, which represents millimeters on one of the scales of the calculator, is made to coincide with the number of divisions on the other, any number representing millimeters on the same scale as 40 will coincide with a number that represents degrees of the quadrant on the other scale. A table of dimensions of the cranium of the cat and rhesus monkey with their coefficients is given here.

Dimension	Coefficient
16 mm.	2.5
18 mm.	2.2
20 mm.	2.0
22 mm.	1.8
24 mm.	1.6
26 mm.	1.5
28 mm.	1.4
30 mm.	1.3
32 mm.	1.2
34 mm. 36 mm.	1.1
38 mm. 40 mm.	1.1
42 mm. 44 mm.	.9
46 mm. 48 mm. 50 mm.	.8
52 mm. 54 mm. 56 mm.	.7

Rule for Setting Gratings by Quadrant Scale.—Set the scale at 40°. In the given dimension find the difference between the standard and selected heads in millimeters. Multiply the number of millimeters by the coefficient for that dimension; the result is the number of degrees which must be added to 40, or deducted from it, as the dimension of the selected head is greater or less than the standard.

CHAPTER VII

ILLUSTRATED DESCRIPTIONS OF INSTRUMENTS (CONCLUDED)

Mechanical Calculator (Pl. XXXVI); Stereotaxic Instrument for Spinal Cord (Pls. XXXVII, XXXVIII, XXXIX); Operative Procedure

MECHANICAL CALCULATOR (PL. XXXVI)

The simplest and cheapest form of stereotaxic instrument that can be made is probably a rectilinear machine constructed on the same lines as that described here, engraved with millimeter scales which are employed for the measurement of all movements. These scales require correction for size, possibly in three dimensions, and it is irksome and unsatisfactory to make repeated calculations, however simple, in the course of an operation, especially when a large number of observations are recorded, as in stimulation experiments. In order to avoid this, the extensible scales of different forms, already described, have been introduced. Another method is to use millimeter scales and correct them with a mechanical calculator; this will not prove so convenient as the adjustable gratings, but it is inexpensive and, where economy is of importance, its advantages and drawbacks are worth consideration. There are several forms of such calculators; the slide rule is the most familiar and perhaps the most complete, but it cannot be set quickly nor read conveniently while operating. A much better one for our purpose is the quadrant calculator (Pl. XXXVII). It was shown me by Mr. Vellacott and can be made, if desired, by anyone, with a sheet of cardboard; it can be set much more rapidly than a slide rule and placed where the operator can read it, without moving or interfering with his work. It consists of two scales; One, made of celluloid or cardboard, of quadrant form (1), is ruled, parallel to the vertical side of the quadrant, with equidistant lines dividing it into 100°. As the gratings of the indicator are set by quadrant scales, to avoid any confusion it will be convenient to call this scale the table or constant scale. The other scale is formed by a sector (2), pivoted to the corner of the quadrant and graduated with somewhat larger divi-

sions. In the pattern shown here, the divisions, compared with those of the table, are in the proportion of 5 : 4, but this is not essential and for our purpose the divisions might be the same in both scales. By inclining the sector, its highest number—80 in this case—can be made to coincide with any degree on the table from 1 to 100, and any lower number on the sector can be made to coincide with any degree on the table below that with which it coincides when it is horizontal, *i. e.*, at its full length. The sector, therefore, is an elastic scale, measuring 100° of the table when extended (horizontal), but shortened by inclination, if desired, till it measures only 1°; but whether it reaches 1° or 100°, it divides that distance into 80 equal parts. Of course, this also applies to any number on the sector below 80 and since the divisions, though different in the two scales, are uniform in both and those on the sector are all affected equally by any inclination, the proportion of numbers which coincide throughout the scales is always constant. Thus, if 80 on the sector coincides with 60 on the table, 40 coincides with 30, 20 with 15, 10 with 7.5, etc.

It will be evident that, within the limits of the scales, the solution of any proportion sum, or vulgar fraction, can be read off at sight. For as any number on the sector is to the number with which it coincides on the table, so is any other number on the sector to the number with which it coincides.

As regards fractions, suppose we want 37/79 of 83. Find 83, the whole number, on the table and make the denominator 79 on the sector coincide with it. Every division of the sector is now 1/79 of 83, the number 37 on the sector represents 37 of these parts and it coincides with 38.8 on the table, which is the answer.

Put in the form of a rule, it may be stated as follows:

Find the whole number on the table and the numerator and denominator of the fraction on the sector. Make the denominator coincide with the whole number on the table, then the number the numerator coincides with is the required fraction.

The application of this device to such purposes as correcting the millimeter scales of the instrument for heads of different sizes, or finding the number of degrees on the quadrant scales of the indicator, equivalent to millimeters, representing the difference between corresponding dimensions in various heads, will be recognized in the following examples:

An operator is using the rectilinear instrument with millimeter scales. He finds that in the selected animal, a rhesus monkey, the prefrontal longitudinal measurement is 53 mm.; in the standard it is 50 mm. He finds, by the chart, that the point to which he wants to direct the needle is 23 mm. in front of the interaural line in the standard. How many millimeters does that represent in this animal? Obviously, the number has the same ratio to 23 as 53 in his animal has to 50 in the standard. If he makes 50 on the sector coincide with 53 on the table, 23 coincides with 24.3 and he racks the needle on the longitudinal scale to 24.3 mm. In a stimulation experiment it may be necessary to measure a number of points in the longitudinal dimension. The sector having been set at 50—53, the correction of any further numbers in that dimension can be read off without altering the calculator.

For setting the gratings of the indicator, it has been explained (Chapter VI) that this can be done quite quickly by direct measurement, and still more conveniently by using quadrant scales, in which case, as the difference between two corresponding dimensions is expressed in millimeters, these are converted into degrees of the quadrant scale by multiplying them by the coefficient for the dimension. A table of such coefficients is given. In the absence of such a table the calculation is a very simple one, but it may save trouble to use the calculator. It is applied as follows:

It has been explained that each dimension of the cranium of either monkey or cat always has the same number of divisions, whether millimeters or coordinates. They are represented, therefore, in a grating, by a constant number of divisions, which are millimeters in the standard animal and may be more or less in others. Adjustment of 1° of the quadrant scale varies every division of the grating 1/40 mm. So, a dimension represented by 40 divisions will be varied 1 mm.; one of 20 divisions, .5 mm. and one of 10, .25 mm. In other words, with a dimension of 40 divisions, 1° of the quadrant is equivalent to 1 mm., and if the dimension has more or less than 40 divisions, a degree will be equivalent to more or less than 1 mm., in the ratio of the number of divisions to 40. Suppose that we want to know how many degrees of the quadrant will alter a given dimension a given number of millimeters. Stated as a proportion sum. As the number of divisions of a given dimension: 40 :: the number of millimeters: the number of degrees. The figures are usually so small that to state

the question in that form is to answer it, but, if preferred, it can be read off on the calculator. Find the number of divisions of the given dimension on the sector and bring it to 40 on the table, then the number of millimeters on the sector will coincide with the number of degrees on the table. Of course, if it is more convenient to make the number of divisions of the dimension on the table coincide with 40 on the sector, the number of millimeters on the table will coincide with the equivalent degrees on the sector. A very little practice with the calculator makes the use of it for such purposes perfectly simple. The equivalent number of degrees must be added to or deducted from 40, and the quadrant scale set at the resulting figure.

A cheap and simple form of indicator has been described (Chapter VI), in which a card ruled with square millimeters is substituted for the adjustable gratings. It has the disadvantage of all fixed scales that it has no provision for corrections for size, which must be made by calculations or other means; the calculator serves this purpose, applied as described for correcting the millimeter scales engraved on the rectilinear instrument.

The calculations required to make the corrections which have been discussed are so simple that the reader may consider there is no need for any of the devices suggested; nevertheless, in practice, he may come to a different conclusion; it is not the trouble of making trifling calculations, which is little enough, but it distracts attention from important matters. In an excitation experiment on the brain a stimulus may give rise to a complex of muscular contractions, which may occur simultaneously in various parts of the body and only last a moment. It may be impossible for one observer to follow them all, but practice, by concentrating his attention, and the knowledge of what to look for, enable the trained observer to recognize a good many simultaneous movements. He must analyze, formulate and record them quickly and everything must wait till he has entered them in his notes. It is easy to record details like the time from a clock, or the date from a calendar, more or less mechanically, but even a simple calculation distracts attention and breaks the train of thought. Automatic correction is the best, calculation the most objectionable. A mechanical calculator is a compromise which, without securing all the advantages of the first, avoids some defects of the second.

Stereotaxic Instrument for Spinal Cord (Pls. XXXVII, XXXVIII, XXXIX)

A stereotaxic instrument for introducing insulated needles for electrolysis, or stimulation of small areas or tracts in the spinal cord.

These plates illustrate an instrument for applying the principles, which have been explained, to the spinal cord, on lines which are essentially similar to those adopted for the brain. The instrument consists of a cradle (1), with four legs terminating in rather blunt points which are curved inwards. The legs are moved on pivots toward the middle line by levers (2, 3, 4, 5) fixed with rack and pinion. By these four grips, the cradle can be quickly and firmly attached to the vertebræ. The cradle supports a travelling stage (10), parallel to the surface of the cord, which carries a needle-holder, and there are two graduated movements in the plane of the stage and one perpendicular to it, by which the needle is directed to any required point. The topographical method employed is also somewhat similar to that described for the brain. The objective point is localized in a transverse section of the cord, perpendicular to the stage and parallel to the needle, or in a chart of the section photographed to scale. This transverse section may be regarded as a lamella and the needle is brought opposite to the edge of it by the longitudinal movement of the stage parallel to the spine. The needle is then directed to the objective by two movements: (a) The transverse movement of the stage and (b) the extension of the needle in its sheath (23). The objective point is identified by millimeter measurement from two zero lines, one of which corresponds to the longitudinal division of the cord, connecting the anterior and posterior median fissures. Assuming the prone position of the animal, the spine horizontal with its dorsal aspect uppermost, this is called the vertical line, the other perpendicular to this, like the crossed line of the letter T, rests on the surface of the posterior columns. The lateral distance of the needle from the first or vertical line is measured by the horizontal scale and adjustable index on the back of the sheath, which records the lateral movement of the needle from a zero, set to correspond to the posterior median fissure.

Balance Gauge.—The depth or distance of the needle from the second or horizontal line is given by a scale (19) and adjustable index on the bed (14) which record the extension of the needle from a zero, set to correspond with the surface of the posterior columns, when the stop and point of the needle are just in contact with them.

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It is evident that the vertical or extension movement of the needle must be parallel to the first or vertical zero line, and as we cannot depend on fixing the cradle so accurately as to secure this, it is provided for by the balance gauge (9) which fits the sheath (23) of the needle-holder. This consists of two vertical parallel rods carried on a brass plate, from the front of which project two small transverse shelves, both perforated with holes for the two rods, which move freely in them in a direction perpendicular to the stage and the surface of the posterior columns. The lower extremities of the rods, 2 or 3 mm. apart, rest on the posterior columns of the cord; their upper extremities terminate in small cross-plates; and when these two cross-plates are level, the rods are perpendicular to a line connecting their lower ends, which are resting on the posterior columns; *i. e.,* the second, or horizontal, zero line. In order that this position may be secured and maintained for any movement, with any needle, the sheath (23) is pivoted and swings on a quadrant (8) and can be fixed at any point by a screw (not seen in the illustration). The front of the plate is ruled with horizontal lines, which show when the T-pieces on the tops of the rods are in line.

Direction of Needles.—In practice, when the carrier has been brought to the required section or lamella, by the longitudinal movement of the stage effected by the screw (12), the balance gauge is introduced and adjusted by the transverse movement till the ends of the rods rest on the posterior columns of the cord. The T-pieces are brought into line by adjustment of the sheath in the quadrant and the latter fixed with the screw. The gauge is now removed and the pilot needle, being introduced, will be perpendicular to the transverse zero line and, of course, parallel to the vertical one. A preliminary puncture of the membranes and cord is made by the pilot needle (11), which is then removed and the insulated needle introduced in its place. The point of the insulated needle is made level with the surface of the stop (21), the needle-holder is pushed down in the sheath till the stop is in contact with the surface of the posterior columns of the cord, and the adjustable index (20) is set at zero on the scale (19) of the bed. The needle is then projected by means of the screw (22) to the correct depth from the horizontal zero line shown by the scale (19) on the bed (18).

Suggested Improvement.—There are one or two defects in this instrument which must be corrected as soon as possible. The principal

one is that it is necessary to expose the vertebræ for about 5 cm. to fix the cradle by these grips. This involves a fairly large wound, so that, in its present state, the instrument is not applicable to animals which are allowed to survive the anæsthetic and should not be employed for degeneration experiments. But it seems practicable to substitute needle grips for those now employed. They will puncture the skin and hold the cradle sufficiently firmly to the spine, without exposing it beyond the smallest median incision sufficient to give access to the very limited area required.

As the travelling stage, with the electrolytic and other needles, can be fitted to any cradle, the alteration required will be very slight and will not affect the rest of the instrument.

It is probable that for the small but deep wound required to reach the cord, some special retractors or specula may be necessary. To divide the laminæ of one vertebra which should be sufficient, a small trephine or fine bone forceps with long points will be most suitable; and as it is not very easy to define the posterior median fissure without dividing the membranes, which is undesirable, a pair of fine, curved blades will be fitted on to a pair of forceps or calipers attached to the stage. They will be introduced on both sides of the cord and support it with very light contact. The lateral movements of the needle will be directed by a small gauge, extending across the cord from one blade to the other. The details of this procedure have yet to be worked out.

The adaptation of these needle grips for securing the cradle and facilitating the introduction of the electrolytic needle to the spinal cord through a small wound should not present any serious difficulty; but it is an object of real importance, because the infliction of a relatively large incision is at present the only obstacle to a very precise application of the degeneration method to the cord and the development of a promising field of anatomical investigation. In other respects, the requirements of this method are amply provided for; there is no reasonable limit to the fineness of the electrolytic needles and precisely circumscribed, pin-point lesions can be produced anywhere. The restricted field involved and limited range of the needle are very favorable to accuracy. With a little practice, by making a series of from 12 to 20 separate experiments applied to one small area and finally determining the exact locality of the lesions in sections,

with the microscope, there is no tract too small to be precisely differentiated and its course completely traced.

Operative Procedure

Sterilization of Instrument.—In performng operations with the stereotaxic instrument there are several details, such as the introduction of the ear cones and treatment of the ears, the measurement of the cat's head, order of procedure, etc., which will be new to all or the majority of my readers and must be explained. Some of them have been mentioned in the description of the parts of the instrument with which they are associated, but presented in a rather disjointed form which an intending operator would have to pick out. Hence it may be useful to bring them together in a connected account of the steps of an operation. This account is specially applicable to the cat, but the procedure is generally very similar in other animals; peculiarities, like certain measurements of the head, and introduction of the ear cones, so far as they are exceptional, require special adaptations in the cat. If an aseptic operation is required, the first point is the sterilization of the instruments. The stereotaxic instrument will not bear frequent boiling, nor is this necessary; except at a few points, it is never in contact with the head, though it affords valuable protection to the wound, which is usually so small and requires so little manipulation that it ought never to be contaminated. The whole instrument should be carefully cleaned after use, washed with boiling water, dried with a soft cloth which has been boiled and dried in an oven, and placed in a bath, large enough to cover it, of strong alcohol, in a vessel provided with a well-fitted ground-glass cover. Parts that come in contact with the head, such as the mask, ear cones, guides, grips of the lateral screw clamps, trephines and forceps and also the pilot and other steel needles, should always be very carefully cleaned and boiled before they are put in the spirit bath. The ivory bed of the needle should be removed from the inner sheath; the latter terminates in the stop which may touch the wound; this part can be held in boiling water for a short time before the whole sheath is placed in spirit. The extensible and ivory scales and ivory bed of the needle cannot be kept in alcohol, but they should never come in contact with the head of the animal nor the hands of the operator when they are in position. They may be cleaned with a boiled rag dipped in 10 per cent formaldehyde and then in boiled water. Plati-

num and glass needles are best sterilized in pure nitric acid and then boiled water.

Preparation of Animal.—Cats which are to be operated on aseptically should always be prepared, if possible, a few days before the operation, their heads shaved and measured and the ears thoroughly cleaned under an anæsthetic. These preparations take longer than the operation; the animal must be fully anæsthetized the whole time, and it is inviting gratuitous disadvantages to add the depression of prolonged anæsthesia to that incurred by the operation itself. If the preliminaries have been carried out previously, the instrument made ready and the extensible scales adjusted, as soon as the animal is anæsthetized the ears can be quickly washed again (or this may be omitted), the skin, where it has been shaved, washed with spirit and painted with tincture of iodine, the ear cones introduced, the instrument applied, and the operation quickly completed. It is impossible to exaggerate the importance of reducing the shock of the operation by every means in our power. This is desirable on various grounds, not the least of them being that compensation so quickly masks the disabilities produced by a small lesion, that rapid recovery, permitting early examination, may afford information of the greatest value which would otherwise be overlooked.

Treatment of the Ears.—The ears need careful treatment and should be attended to some days before an operation. It is impossible to sterilize a cat's meatus efficiently, and as the introduction of the ear cones requires some manipulation, unless care is exercised there is a risk of septic infection. The ears should be thoroughly washed out with hot water and soap applied with a very soft shaving brush. The skin is thin and may be excoriated if a stiff brush is used. After the soap has been washed away, the cavity, especially the deep parts, should be dried with absorbent cotton and then painted with an antiseptic ointment. Equal parts of boric acid and oxide of zinc, mixed to the consistency of thick cream, with olive oil, glycerine and water, with the addition of 1 per cent of lysol, serve the purpose.

Application of Mask.—The mask (Pl. II) is first fitted on. The orbital brackets (9) are made to correspond to the centers of the orbits, over the lower margins of which they are hooked. The bit (8) is inserted in the mouth behind the upper canine teeth. The screws (16) are passed through the slots and secured moderately firmly by the split nuts (11).

Introduction of Cones in Cats.—The auditory meatus in cats, especially in old ones, where it is deeply sunk between the mastoid process and masseter muscle, is not very accessible. The pinna forms a deep funnel tapering to quite a small apex and the opening of the meatus is not exactly at the point, but joins it rather obliquely, the folds are irregular and the orifice is further concealed by cartilaginous lips, so that it is merely a slit which may be invaginated by the blunt point of the ear cone. Moreover, as the outer part of the meatus is composed of cartilage and loose fibrous tissue, if the cone is not introduced in the axis of the bony canal it may miss it and lodge in the tissues, although it has entered the orifice. The easiest plan is to split the funnel by cutting the anterior inferior aspect of the pinna down to the apex; this exposes the orifice of the meatus and makes it easy to insert the cone; but it is an objectionable proceeding if the animal is to survive, because it leaves an open wound which may bleed freely and is liable to septic infection. The necessity, however, can be avoided with a little trouble. It is sometimes advisable to use a guide like that shown in the illustration (Pl. I, 1). The guide is a small steel bar 3 mm. wide fixed at an angle with the handle and is passed into the meatus with or without the aid of a speculum (Pl. I, 111).

Speculum and Guides.—It is easy to introduce the guide without the speculum, but groping is objectionable on account of sepsis and it is difficult to make sure that the guide is in the meatus unless it penetrates to the fundus, which involves perforating the membrana tympani. This is not of very much consequence, but it is preferable to avoid it, so the best plan is to expose the orifice with the speculum, pass the guide a few millimeters into the canal and, holding it there, withdraw the speculum. Keeping the guide in position, another handle terminating in a round probe is used to introduce the cone; the probe is inserted into the lumen of the cone and projects 2 or 3 mm. beyond its point. There is a slot in the disc which is slipped over the heel of the guide and, when fitted on, the point of the cone hugs the guide, slides easily down it, and must enter the meatus; as it is pushed home the guide is gently withdrawn. The cone is held in the meatus by the probe until the clasp (Pl. III, 20) is applied and it holds the cone securely in its place till the head is in the frame, when it is removed.

The funnel-shaped pinna in its natural position is more or less flattened or telescoped and thrown into folds. To expose the orifice

of the meatus as much as possible these folds should be straightened by drawing the pinna directly outwards.

The method described with the guide is the most certain way of introducing a cone and it is advisable to have the guide at hand and to know how to use it in case of exceptional difficulty, but it is usually unnecessary. If the pinna is drawn outwards, as advised, and the cone is introduced on the probe, the opening will be found in most cases without difficulty. If it gives any trouble, the best plan is to expose the orifice with the speculum and then pass the probe and cone as the speculum is withdrawn. The apex of the funnel of the auricle is so narrow that there is not often room for both cone and speculum together. The advantage of the guide is that it can be introduced by sight while the speculum is in position and exposing the orifice of the meatus.

Anatomy of Meatus in Cats.—Questions may naturally occur as to the effect of these manipulations on the internal ear and membrana tympani and, to answer them, it is necessary to enter into a brief explanation of the anatomy of the parts in the cat. The direction of the meatus is nearly transverse, but the axes of the two tracts converge to a point slightly in front of the interaural line. The canal terminates in the huge bony air cell, seen in many sections in the atlas, which has been described as the bulla ossea. In shape it is something like a hip-bath, deeper behind than in front, with the edges bent over to form a rounded rim, projecting above the level of the membrane, which is attached to the edge and stretching across the oblique opening extends downwards, forwards and inwards, at an angle of about 45° with the interaural line. The posterior margin of the membrane extends some 8 mm. further out from the median line than its anterior insertion, and at the latter point the cava tympani, the space between the membrane and the inner wall of the bulla, is not more than 2 or 3 mm. deep. Near the posterior attachment of the membrane, where the roof meets the posterior wall of the meatus, the head of the malleus is articulated and its handle, which is exceptionally long, accompanies the membrane almost to its anterior insertion, pointing in the direction of a lower molar tooth on the opposite side. The labyrinth is above and behind the head of the malleus; it is quite out of reach and need not be considered. The cones are not long enough to reach the membrane and if they were it would be difficult for them to perforate it owing to

its obliquity. If the guide is made to penetrate far enough, it punctures the membrane in the anterior inferior quadrant near the tip of the manubrium and is immediately brought up by the inner wall of the bulla. I dissected one or two specimens where this occurred, to see the effect, and at first could not detect the puncture, but found there was a valvular opening in the situation indicated through which the guide had passed. The membrane is thin and not very vascular, the slight rent could make very little difference to the animal and was obviously of small importance.

A more serious matter is the practical impossibility of sterilizing the meatus and therefore the less manipulation there is in it the better. It is desirable to introduce the guide and cones without groping and a beginner should practise it in some animals which are to be destroyed while still anæsthetized, before attempting it on one which is to be kept alive.

Application of Head Instrument.—The mask having been fitted on and secured moderately firmly with the screws and the cones introduced, the next step is the application of the *head-vice* (Pl. V, VI, VII), which is suspended by four springs and supported on a stand. It is brought directly over the animal and lowered till the head can be easily raised into it. While an assistant steadies the frame, the operator lifts the head from below and slides the conical extremities of the aural pivots (Pl. V, 26) into the orifices of the ear cones, making sure that they are well home. The horizontal arms (14) of the mask are raised till they are in contact with the under surface of the lateral bars of the frame and fixed there with the clamps (Pl. VI, 46) provided for that purpose. These clamps must be fixed at the same distance from the pivots, *i. e.,* the interaural line, the lateral bars (22) of the frame being graduated with this object. It will be seen at this stage that the basal zero plane of the cranium coincides with the upper surface of the head-vice. The occipital bar (Pl. VI, 24) is brought forwards till it is in contact with the occiput and clamped, at the same distance from the interaural line, on both sides. The cranium is then centered with the four screw clamps (Pl. VI, 27-30) and the aural pivots (25), which are all graduated and can be easily read from the same point in front. The screw clamps should be slipped up as far as they will go, followed by the screw nuts (28-31), and a turn or two of the latter will secure a firm grip of the head. They must be adjusted to exactly the same reading on both sides, and

when the screw clamps and aural pivots read exactly the same on both sides, the sagittal zero plane of the head and the median longitudinal plane of the frame must coincide. All screws must now be fixed and the position of the head in relation to the frame carefully inspected. If this is not true, there must be some error in the application which must be looked for and corrected. The cage (Pl. X) is next dropped into its slots (42, 43) and fixed by the four screws (44, 45), and the cranium is then measured with the needle-gauge (Pl. XXII) from above, from both sides and from behind. The anterior longitudinal dimension of the cranium in the cat cannot be measured directly without opening the frontal sinus, but we may estimate it approximately by the posterior margins of the orbits (Chapter V). One method of measuring the latter is with screw rods (12, 13) attached to the mask, the rods terminating in clefts which engage the margins of the orbits. This method is shown in the illustrations; the posterior margins of the orbits can also be measured directly with a gauge (Pl. XXXIV, 34), which is preferable.

Setting Scales.—Having measured the cranium the figures are compared with those of the standard head. When they are identical, or nearly so, millimeter measurements are employed for that dimension; but if they are greater or less than the standard in any dimension, the extensible scale (Pl. IX), which corresponds to it, is set so that its divisions measure more or less than millimeters in the same proportions. The scales, having been set, are inserted in their clamps in the travelling stage (Pl. XIII, 84, 85) and the needle-holder (Pl. XIV, 112).

Traversing Stage.—The traversing stage (Pl. XIII) is then applied to the cage in the position required for introducing the needle, having regard to the point to be reached, and the direction by which the needle is required to approach it, (Pls. X, XI, XII). The traversing stage is fixed to the cage in any desired position by means of steady pins and two clamps (Pl. X, 90). These must be firmly secured. If the pilot needle is to be used (Pl. XVI, 1), it is next attached and by the two movements of the traversing stage is brought directly over the objective point in the cranium, the stop (97) pushed down a convenient distance and the needle racked through the stop till it reaches the bone, which has been exposed by a small incision through the integuments.

Pilot Needle.—The point of the pilot needle indicates the center of the trephine hole which is to perforate the skull. This point should be marked with a fine drill set in the rectangular handle of the dental engine. It is made to penetrate a short distance into the bone exactly where the pilot needle touches it. Having marked this spot, the pilot is withdrawn and racked out of the way by the traversing stage, leaving the head exposed sufficiently to allow the application of the trephine. The trephine is fixed to the dental engine and the small disc of bone removed; the hæmorrhage, which may be considerable for the size of the wound, is checked. Then the pilot needle is brought back to the original position and racked down through the dura till it reaches the objective point, which is known by the scale and index of the rectilinear needle (Pl. XIV, 111, 112, 113).

Setting Rectilinear Needle.—When these have been set and the adjustable index (113) on the bed of the needle reads both the ivory and extensible scales at once, they are required to show, at any time, the distance of the point of the needle from the zero plane parallel to the stage in millimeters and in coordinates. To secure this we must: (1) See that the point of the needle is exactly level with the stop (97); (2) slide the latter down, by the movement of the inner in the outer sheath, to the point required close to the dura or touching it, and lock the holder with the milled head (96); (3) read the distance of the stop from the zero plane, with the scale of the stop and arrow on the side of the inner sheath; the point of the needle is the same distance and we must, therefore, (4) set the adjustable index (113) to read the same on the ivory scale (112); (5) see that the spiral, which is to represent zero in the spring scale, corresponds with zero in the ivory scale. Then in any position of the needle point the ivory scale (112) will show how many millimeters it is from the zero plane, the extensible scale (111) how many coordinates or corrected millimeters. We know from the chart how many millimeters or coordinates the objective point is from the zero plane; and whether we use millimeters or coordinates the number is always the same. So we have only to rack the needle down till the index reaches the same number on the scale in use, and the point of the needle will have arrived at the objective. The pilot needle is now withdrawn and for interchanging needles it is advisable to remove the inner sheath by relaxing the milled head (96) and pulling the whole sheath and needle out by it. The pilot with its bed is removed from the

inner sheath and the electrolytic or other form of needle already mounted on its own bed is substituted for it, the point of this needle must also be made to coincide with the surface of the stop; it is then introduced again into the outer sheath, pushed down till the stop is in the previous position, which must be verified by looking at the scale on the inner sheath, and locked. If the position of the stop is altered the adjustable index must, of course, be altered accordingly, and the operator must never forget to see, when reading the scale on the inner sheath and setting the adjustable index, that the needle and stop coincide and that the zeros of the ivory and extensible scales do the same.

Inclined Needle.—This procedure applies to any rectilinear movement of the needle; if the needle is inclined, the method of measurement is different. The objective point is located in a lamella parallel to the plane of inclination of the needle and perpendicular to the stage, the needle is brought to this lamella by one of the movements of the stage which may be called its first movement and is measured by the extensible scale, if that dimension of the head differs from the standard. There remain the second movement of the stage and the two extension movements of the needle in its sheaths, to bring the point to the objective. The measurement of these movements is ascertained by the indicator and copied in the instrument. They comprise the angle of inclination, length of needle and number of millimeters from zero of the scale which records the second movement of the stage. These readings are always in millimeters, because the correction for size in both dimensions of the lamella is effected by the adjustable grating of the indicator and, therefore, extensible scales are not required. The adjustment and application of the indicator having been fully described elsewhere (Chapter VI), it is enough to say here that the grating of the indicator represents the lamella and is adjusted to correspond with its variations of size; the objective point is located in it by measurement from zero bars which represent the two zero planes and are used for the same purpose. A frame, carrying a finder needle and graduated quadrant, exactly reproduces the needle and its movements in the instrument, with the advantage that it can be directed by sight. The finder needle is set at the required angle with its quadrant, moved on a guide which corresponds to the second movement of the stage and extended by a measured projection from its pivot till it reaches the objective point in the

grating. The process is exactly repeated in the operating instrument; the needle is set at the same angle by the quadrant, moved the same distance from zero by the second movement of the stage, the first having been employed to bring it to the lamella represented by the grating, finally extended the same distance from its pivot, and the result must be to bring it to the same objective point in the lamella which it has reached in the grating of the indicator. The extension of the needle in the stereotaxic instrument is read by the millimeter scale of the inclined needle on the left of the bed (110) and an adjustable index (Pl. V, 79) attached to the outer sheath. The excursion of the bed in the inner sheath and of the inner in the outer sheath both affect the relation of the scale on the bed to the index on the outer sheath equally, so that the two movements are practically identical and are read indifferently from the same scale and index. This adjustable index is set as follows: The point of the needle is made to coincide with the extremity of the stop, the pivot stop line (marked *P. S.* on the back of the inner sheath) is made level with the top of the outer sheath; this brings the stop and point of the needle level with the center of the pivot, and the adjustable index is then set at zero on the indicator scale (on the left) (Pl. XIV, 110). It will register the distance of the point of the needle from the pivot, whether the former is moved by racking it through the stop or by sliding one sheath in the other. Whichever needle is employed, it is racked through the stop to the objective point, which has already been reached by the pilot. The subsequent manipulation is explained in the separate description of each variety of needle.

Equatorial.—(Pl. XXX.) When the equatorial is employed, the foregoing procedure requires little modification. After the head has been adjusted in the head-vice, the gauging and drilling cage (Pl. XXXIV) is applied and the dimensions of the cranium taken with the needle gauge (26) fitted to that instrument. The gratings (8, 12, 16) of the three-dimensioned indicator (Pls. XXVII, XXVIII), which is always employed with the equatorial, are set in accordance with the measurements of the cranium and the index point is defined by the index needles (Pl. XXVIII) in accordance with the measurements of the objective ascertained by the chart. The index point is fixed in this position and the vertical screen (16) and horizontal index needle (28) are removed, leaving the index point exposed and easily approached from any position by the operating

needle in the equatorial. The equatorial carrying the pilot needle is then applied to the slots of the indicator and fixed with the clamping screws. The pilot needle is set at any required angle and directed from any selected position and projected till its point is in contact with index point; all clamping screws of the equatorial are now fixed, the length of needle projected to make contact with the index point noted on the scale and the needle then retracted sufficiently to be out of the way. All this can be carried out a day or two before the operation, and it is desirable that this should be done so that the actual operation may be performed as quickly as possible; but in any case when the equatorial has been set in the way described, it is transferred bodily from the indicator to the corresponding slots in the head-vice, fixed, and the pilot needle projected till the point touches the cranium and the point of contact marked with ink or a small drill. The pilot needle can then be retracted again as far as convenient or the whole equatorial removed while the cranium is trephined at the marked point. A 5 mm. trephine is usually sufficient, the crown of bone is removed and any hæmorrhage from the diploe arrested. The equatorial is then replaced, if it has been removed, and securely fixed, the needle is pushed in till the stop is close to the cranium, where it is fixed, and the needle is racked in through dura and brain till the index reaches the number noted on the scale of the needle, when the point of the pilot will be at the objective. The pilot is then withdrawn, another needle substituted, and the required operation completed. If duplicate equatorials are employed, one is applied to the indicator and the other to the head-vice, the steps of the operation are carried out in the indicator and precisely repeated by means of the corresponding scales in the instrument attached to the head.

I hope that as the application of this method becomes known, some medical men with clinical experience who encounter interesting problems in the anatomy, physiology or surgery of the brain, but who have been deterred from attempting to solve them experimentally from want of technical training, may be encouraged to undertake such investigations when they realize how easily, with ordinary surgical knowledge and a little practice, the necessary operations can be performed with the machine. For those who have had no previous experience of operations on animals a few practical suggestions may be useful.

Anæsthesia.—Compared with the monkey the cat is a bad subject for anæsthesia. It is apt to collapse under chloroform and to get the bronchi choked with excessive secretion under ether. In various laboratories certain routine methods of producing anæsthesia are in favor and, when this is the case, it is generally advisable to follow them. A very satisfactory method is that of sending a current of air from an automatic pump through a Woulfe's bottle containing chloroform alone, or mixed with ether, affording a regular supply of dilute vapor of constant strength. Another plan often adopted is to give a preliminary dose of paraldehyde by the mouth or urethane or morphia by hypodermic injection; full doses produce a heavy sleep in which a very small quantity of chloroform at fairly long intervals is sufficient to maintain prolonged and deep anæsthesia. This is useful when it is necessary to keep the animal anæsthetized for a long time, as in stimulation experiments, but with operations from which the animal is to recover it is not advisable, and inhalation of a mixture of chloroform and ether or A. C. E. as the only anæsthetic is preferable. Great advantages are claimed for various inhalers; most of them give a dilute vapor of fairly constant strength, which is the important thing, and they have arrangements for increasing or diminishing the strength of the vapor at will with more or less accuracy. A cloth folded into a cone or a piece of wool in a wide-mouthed bottle will serve the purpose well enough. Cats should be anæsthetized to begin with under a large bell glass which easily covers them, they will submit to anæsthesia so induced repeatedly without any sign of fear or aversion, but to hold the animal down and begin the administration with an inhaler excites fear and resistance and probably necessitates a larger dose of anæsthetic. Once it is applied the anæsthetic should be administered continuously until the animal is fully narcotized.

Overdose Fallacy.—The belief, which has been sedulously inculcated and widely accepted, that death from chloroform is invariably due to an overdose, in quantity or concentration, is a mischievous fallacy that has probably been responsible for more fatalities than any other error. Dr. Goodman Levy,[8] who has made many valuable observations on this subject and whose work is well known and widely appreciated, has proved that an insufficient dose of chloroform is an effective cause of ventricular fibrillation which is prevented by a more liberal administration. His experiments which are described in numerous papers

are convincing, but apart from his precise and critical methods a very moderate experience should make two things clear to everyone but those who can see nothing but what they want to: (1) That in many of the cases of death from chloroform the possibility of an overdose can be absolutely excluded; (2) that when it occurs in such circumstances the symptoms are quite distinct from those due to an unquestionable overdose.

In trifling operations in man when the surgeon is content with very light anæsthesia, the administrator is cautious and the narcosis purposely incomplete, the possibility of danger is notorious; and in animals, especially cats, when an anæsthetic is resorted to merely for convenience, to keep the animal quiet in a procedure which could not cause pain, while chloroform is being administered most sparingly and nothing like full anæsthesia has been obtained, the breathing may suddenly stop without warning. Artificial respiration is useless, for when the breathing ceases the heart has already done so and life is extinct. This is quite different from what occurs with an overdose where the subject is fully narcotized; the breathing becomes labored and stertorous before it ceases, the heart generally continues beating and with artificial respiration, inversion, etc., recovery or death may result, but there is generally some response and something like an effort at recovery. In the laboratory, with cats especially, a careful anæsthetist who believes the only danger is from an overdose and has had one or two fatalities, which he is assured were due to that cause though they were really due to his caution, may become over anxious, give a very small dose and frequently remove the inhaler to observe the respiration, keeping the animal fluctuating on the verge of narcosis, which is the very way to produce the result he is so anxious to avoid; whereas a laboratory boy or an inexperienced student will push the anæsthetic freely without any mishap. The safest plan appears to be to get fairly quickly over the borderland of incipient narcosis, to employ a constant vapor containing about 2 per cent chloroform which may be slightly increased till full anæsthesia is established and slightly diminished to maintain it, but applied continuously till full narcosis is established. A practice to be particularly avoided is to get the animal nearly under, then remove the inhaler and let it partially recover.

If it is intended to keep the animal alive after the operation every effort should be made to avoid shock and to secure the most rapid

recovery possible; it is a mistake to hurry, but it is just as bad to waste time.

Hæmorrhage is generally insignificant and hardly ever severe. Large vessels are not often encountered and still more rarely wounded by the needle in the substance of the brain. They are chiefly met with in the diploe and the membranes. A sinus can be avoided by making a small incision in the dura to one side and drawing it out of the way of the needle with a small retractor. Bleeding from the vessels on the surface of the brain and oozing generally can be checked with peroxide of hydrogen 20 vol. strength applied on a small pledget of wool. It is also sufficient, as a rule, to stop bleeding from the diploe, but if this should be obstinate the galvanic plug (Pl. XXXV) can be used. There is no need of irrigation with hot water and it should be altogether avoided. A cat's fur is very long, fine and close, and when it is saturated with hot water it is hard to say how long it takes to dry. The cat's natural aversion to water is probably due to the difficulty of getting dry. No amount of rubbing with cloths is quite effective. It is not a desirable proceeding just after an operation, and to let the animal spend the night with a wet coat is most objectionable. Operations on the brain, by the method described, produce so little disturbance that cats generally recover from them very rapidly.

After-Treatment.—It is advisable to enter in the notes the time an operation is concluded and the animal returned to its cage, how long it is after when it gets up voluntarily and walks about, when it first takes milk and meat, begins to clean itself, and, of course, its condition the following morning. As a rule, it ought to have got up of its own accord and be sufficiently sensible to come when it is called and take milk, in an hour from the time it is put back in its cage, and the next morning, except for any specific disability which is the necessary and intentional effect of some lesion, it should be perfectly well; feeding well, cleaning itself, its coat and eyes bright and able to run about the laboratory, jump off chairs and tables, etc., as if nothing had happened. Of course, we cannot always secure such good results, but an ordinary operation should not be considered satisfactory unless they are obtained. The accident most difficult to prevent is opening the wound before it has healed. Some cats will constantly rub their heads against the wires of the cage and get a dressing off unless it is very secure. A figure-of-eight bandage of narrow adhesive plaster,

passed under the jaws and alternately in front of the ears and behind them is the most effective, but care must be taken not to bring it far enough forward to interfere with the movement of the jaws. If it should be necessary to remove it, the hair, to which it adheres, must be snipped with a pair of scissors. I have made some caps which answer fairly well. Two longitudinal wires passing from just above the orbits to the occiput are fastened to two or three transverse bands of leather or poroplastic which extend across the cranium, one in front of the ears, and one or two behind them; they converge to two rings, one on each side, connected under the jaws with a strap and buckle and the cap is attached to a leather collar. It has the advantage of being quickly applied and removed. The best immediate dressing is a single layer of thin gauze, very little larger than the wound, painted with a thick solution of celloidin extending for some distance over the skin. The celloidin dressing should be very thin, for if several layers of gauze are used and these extend much beyond the wound, they may take half an hour to dry, involving a prolongation of anæsthesia which should be avoided.

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PLATES

REFERENCES TO NUMBERS

PLATE I.—EAR CONES, GUIDE, SPECULUM

FIGURE I

Guide for introducing ear cone in cat.

FIGURE II

Probe for introducing ear cone in cat.

FIGURE III

Speculum for introducing ear cone in cat.

FIGURE IV

Method of applying guide and probe to cone.

FIGURE V

A. Plain straight ear cone for cat. The disc is slotted for the guide as shown in Figs. 1, 2 and 4.

B. Another form of ear cone for cat with an adjustable curved flange which rests against the ramus of the jaw and the masseter muscle.

C. Ear cone for rhesus monkey. The cone is bent at an angle of about 20° to correspond with the meatus, the diameter of which is subject to variation. Two or three sizes of the cone should be provided; the one represented is about the average. The following figures indicate the various parts of the cones illustrated: 1, Cone. 2, Angle. 3, Barrel. 4, Disc. 5, Flange. 6, Funnel. 7, Screw for fixing adjustable flange (5, B). As the corresponding parts on the right and left sides of the stereotaxic instrument are identical, to reduce the number of figures required, the same number is used to indicate duplicate parts on both sides in the following illustrations and each part retains the same number in different plates.

PLATE II.—THE MASK

Parts previously shown retain the numbers assigned them.

8. Bit, placed in mouth behind upper canine teeth. The figure is placed between the slots which receive the screws (16) by which the bit and orbital brackets (9) are made to hold the upper jaw and secure the mask in position.

9. Orbital brackets which are hooked over the lower margins of the orbits and held firmly against them with the bit (8) and screws (16).
10. Pillars which support screw rods (12).
11. Split nuts with conical points and washers (19) which are applied to screws (16) to raise bit (8) against counter pressure of orbital brackets (9).
12. Screw rods for measuring posterior margins of orbits, the cleft extremities engage the margins of the orbits; when screwed up, the base of the cleft is in firm contact with the margin of the orbit and the stud (15) indicates this point and can be measured from the front of the cage with a depth gauge. The margin of the orbit can be measured directly with a depth gauge fitted with a small transverse bar at its extremity and this method is perhaps more convenient especially with the measuring cage (Pl. XXXIV).
13. Screws for adjusting screw rods (12).
14. Horizontal arms which are held in contact with lower surfaces of lateral bars (22) of head-vice (Pl. VI). When they are in this position the upper surfaces of the lateral bars are level with the lower margins of the orbits.
15. Studs corresponding to the bottoms of the cleft extremities of screw rods (12) and consequently to the posterior margins of the orbits which they serve to measure.
16. Screws which pass through the slots in the bit (8) and with the split nuts (11) hold the bit (8) and brackets (9) together and secure the mask.
17. Front of mask formed by a sliding joint (17) which regulates the distance between the orbital brackets (9). The joint is fixed with a screw (18).
18. Screw for fixing sliding joint (17).
19. Conical washer of split nut (11).

PLATE III.—LATERAL VIEW OF HEAD OF CAT WITH MASK

Lateral view of head of cat with mask and ear cones in position ready to be introduced into the head-vice (Pl. VI). The cones are held with a clamp (20) which is removed when the tapered ends of the aural pivots (26) have been inserted into the cones.

The clefts of the screw rods (12) engage the posterior margins of the orbits, the level of which is marked by a stud (15) on the outer surface of the cleft extremity of the rod.

Figures the same as in Plate II.

20. Clamp to hold ear cones in position till the head is fixed in the head-vice.

PLATE IV.—FRONT VIEW OF SAME HEAD AS PLATE III

Numbers as before.

PLATE V.—PLAN OF HEAD-VICE

The mask and ear cones are not introduced.

21. Joints connecting frontal and lateral bars (23 and 22).
22. Lateral bars graduated forwards and backwards from interaural line (shown by needle), so that sliding joints can be fixed at corresponding points on both sides.
23. Frontal bar.
24. Occipital bar.
25. Aural pivots, graduated.
26. Conical extremities of aural pivots.
27. Upper graduated sliding bars of temporal clamps.
28. Screw nuts running on triple thread screws. The clamps which slide in the joints (35) are pushed inwards till they are in contact with the head. The nuts are then run up and screwed home till the head is firmly held between the opposed clamps, the scales of which must correspond.
29. Grips of temporal clamps.
30. Upper graduated sliding bars of mastoid clamps.
31. Screw nuts of mastoid clamps.
32. Grips of mastoid clamps, points inserted on a doubly inclined plane.
33. Sliding joints for front feet of cage.
34. Screws to fix 33.
35. Sliding joints of temporal clamps fixed at required position on lateral bars by screws underneath.
36. Fixed joints of aural pivots which slide in these joints and are fixed with screws underneath.
37. Sliding joints of mastoid clamps fixed with screws underneath.
38. Sliding joints of occipital bar.
39. Screws to fix 38.
40. Sliding joints for back feet of cage.
41. Screws to fix 40.
42. Circular slots for front feet of cage.
43. Circular slots for back feet of cage.
44. Screw heads to lock front feet of cage. They are half cut away to allow cage to be applied or removed without taking the screws out.
45. Screw heads to lock back feet of cage.

PLATE VI.—HEAD-VICE WITH MASK AND EAR CONES

Plan of head-vice viewed from above, showing mask and ear cones in position and illustrating their relation to the rest of the head-vice.

Numbers as before.

46. Clamps to hold horizontal arms of mask in contact with lower surfaces of lateral bars of head-vice.
47. Blocks with screws which can be attached to posterior ends of lateral bars to support the drill when in use.

PLATE VII

Same as Plate VI, but showing cat's head in position, the skin is reflected to expose frontal sinus.

PLATE VIII

Side view of head-vice with cat's head in position.
Numbers as before.

48. Screw to fix sliding joint of temporal head clamp.
49. Screw to fix aural pivot.
50. Screw to fix sliding joint of mastoid head clamp.
51. Screws to fix frontal bar to lateral bars of head-vice.

52, 53. Removable legs of head-vice.

PLATE IX.—EXTENSIBLE SCALES

1. Scale of rectilinear needle.
2. Scale of transverse guide.
3. Scale of longitudinal guide.

55. Spiral spring enclosed in tube.
56. Tube open down one side to expose spirals of spring.
57. Screw rod attached to free end of spring.
58. Neck of tube over which milled head (60) screws and fixes rod (57).
59. Milled head which moves the spiral spring as a whole in the tube.
60. Milled head which screws over neck of tube (58) and fixes rod and spring.
61. Fine adjustment of rod and spring.
62. Ivory millimeter scale attached to tube by spring clip (63).
63. Spring clips.

PLATES X AND XIII

These two plates should be examined together and compared with Plates XI and XII.

Cage, traveling stage and vertical needle in holder. First position viewed from the front.

PLATE X

64. Horizontal frame of cage.
65. Front legs of cage.
66. Back legs of cage.
67. Front feet of cage.
68. Back feet of cage.
69. Frame of traversing stage.

PLATE XI

All parts of the stereotaxic instrument, with stage and inclined needle in sixth position. Stage applied to left face of cage. Viewed from left front. Figs. 65 and 66 should be transposed.

PLATE XII

The whole rectilinear instrument, with stage and rectilinear needle in seventh position. Stage applied to rear face of cage. Needle facing left and viewed from left rear.

140. Switch. Movable and can be fixed to any corner of cage. It receives the two battery leads and directs the current from either, to (I) needle, (II) stop, or (III) frame of instrument as required.

PLATE XIII.—TRAVERSING STAGE

With ivory and extensible scales mounted, but without needle-holder. Viewed from above.

Comparison of these four plates will give a fairly clear idea of the cage, traversing stage, and needle-holder and their relations in various positions.

In using the terms anterior and posterior, front and back, right and left, etc., the stage is assumed to be in the first position—above the cage, the needle vertical and facing forwards. Right and left apply to the head in the frame, not to the observer.

70*a*, 70*b*. Transverse guides of traversing stage both engraved with millimeter scales. The scale on the anterior guide (70*a*) is only used in the fifth and sixth positions where the stage is applied to right or left face of cage and shows height of transverse needle above surface of frame, *viz.*, basal zero plane. The scale on the posterior guide (70*b*) is employed in all other positions. The distance of the needle is reckoned from both sides of a zero in the middle of the scale.

71. Traveling carrier of needle-holder.
72. Outer sheath of needle-holder with V-slide to receive inner sheath.
73. Pinion for longitudinal movement of traversing stage.
74. Screws for fixing longitudinal movement of traversing stage.
75. Pinion for transverse movement of traversing stage.
76. Screw for fixing transverse movement of traversing stage.
77. Quadrant for measuring inclination of needle.
78. Screw for fixing inclined needle.
79. Adjustable index on outer sheath for reading millimeter scale on left of bed of needle-holder, for use with inclined needle. Compare with Plate X.
80. Index for reading the longitudinal movement of stage on three scales: (1) Engraved scale (91) on longitudinal guide; (2) ivory scale (88) which coincides with it; and (3) extensible scale (82) between them.
81. Index for reading transverse movement of stage, on three scales at once, in the fifth and sixth positions; on the engraved scale of the anterior guide, the ivory scale and the extensible scale. In all other positions, on the engraved scale of the posterior transverse guide and the ivory and extensible scales.

82. Extensible scale (longitudinal).
83. Extensible scale (transverse).
84. Sockets for longitudinal extensible scale.
85. Screws to hold longitudinal scale in sockets (84).
86. Sockets for transverse extensible scale.
87. Screws to hold transverse extensible scale in sockets (86).
88. Ivory millimeter scale (longitudinal).
89. Ivory millimeter scale (transverse).
90. Clamp to fix traversing stage to cage.
91. Longitudinal guides of traversing stage, one engraved with millimeter scale.
92. Millimeter scale on anterior transverse guide used in fifth and sixth positions to show height of needle above basal zero plane.

PLATE XIV.—NEEDLE-HOLDER

98. A double-barrelled insulated needle, platino-iridium and glass for stimulation or electrolysis, mounted on special bed of needle-holder with extensible and millimeter scales and electrical connections.
93. Inner sheath in which ivory bed travels by rack and pinion and carries the needle with it beyond the stop (97). The movement is read by an adjustable index (113) and the extensible and millimeter scales (111) and (112).
94. Ivory bed upon which the insulated needle (98) is fixed.
95. Head of pinion by which the ivory bed (94) is moved in the inner sheath (93) and the needle projected.
96. Head of screw by which the inner sheath (93) is locked when required in the outer sheath (Pl. XIII, 72).
97. The stop. It consists of two brass jaws lined with ivory and approximated with the tension desired by means of a screw (99).
98. Point of insulated needle.
99. Tension screw to close jaws of stop.
100. Sliding shunt by which stop can be connected with the terminal (101) for stimulation with live stop.
101. Terminal of lead (118) for bringing stop into circuit.
102. Jaws for centering and holding needle, covered with thin rubber.
103. Eccentric cams which open and shut jaws (102). The surfaces of the milled heads of the cams are marked with lines and when the lines converge at corresponding angles, the jaws are equidistant from the middle line, *i. e.*, the needle is centered.
104. Swinging arm carrying a screw which terminates in a small plate notched above to receive apex of ivory wedge (105). The object, to prevent short-circuiting, has been explained (Chapter IV, Pl. XIV, 104).
105. Ivory wedge, the apex of which is in contact with the end of the double glass tube between the wires of the needle.

106. Terminals fixed on lower ends of brass shoes (107). Slits receive the wires of the needle which are held with screws (106).
107. Brass shoes. Numbers placed close to slots for screws which hold shoes on bed, but permit a sliding movement regulated by screw (109).
108. Terminals for battery or switch leads (116, 117) which are connected through the brass shoes with the wires of the needle.
109. Screw rods fixed by one end to the brass shoes and at the other, passing through two small drums with double-milled discs. The drums revolve in clips and are easily turned with the point of one finger and effect a fine adjustment of the sliding movement of the shoes and therefore of the wires at the point of the needle.
110. Millimeter scale of the inclined needle (it has since been lengthened to 80 mm.). It is read by an adjustable index on the outer sheath (Pl. X, 79) and shows the distance of the point of the needle from the pivot by which the outer sheath is attached to the carrier in the traversing stage. A measurement always employed with the inclined needle.
111. Extensible scale.
112. Ivory millimeter scale. These are scales of the rectilinear needle. When in use a selected spiral is made to coincide with zero of the ivory scale. The index reads the number of spirals and the number of millimeters together. A stop scale is marked on both sides on the adjacent borders of the inner and outer sheaths. It shows the distance in millimeters of the extremity of the stop from the zero plane to which it is perpendicular and is a constant, *i. e.*, a measurement of the instrument. If the needle is racked down till its point coincides with the extremity of the stop and the adjustable index (113) is made to read the same on the ivory scale (112) as the stop scale, that figure must show the distance of the point of the needle from the zero plane in millimeters and the index at the same time shows the number of spirals or coordinates on the extensible scale (111).
113. Adjustable index which reads both scales of the rectilinear needle together.
114. Slide which carries adjustable index (113).
115. Screw to regulate friction of pinion (95).
116, 117. Positive and negative leads from battery or switch to needles.
118. Lead from battery or switch to terminal (101) connected with stop (97) by shunt (100).

PLATE XV.—INSULATED NEEDLES

Three forms of platino-iridium needles insulated in glass tubes, actual size and enlarged.

1. Single needle.
2. Double-barrelled needle.
3. Concentric needle.

PLATE XVI.—CUTTING NEEDLES AND BEDS

I. Pilot Needle and Bed

1. Pilot needle.
110. Indicator scale for inclined needle.
113. Index for rectilinear needle.
114. Slide for adjusting index (113).
118. Screw head serving as handle for introducing pilot needle.
120. Clamp which holds pilot needle.

II. Cyclotome and Its Bed Fitted Into Inner Sheath

1. Shaft of hollow needle.
2. Cylinder which fits into clamp (119).
3. Milled disc which rotates needle (1).
4. Cylinder graduated in millimeters read by lower edge of (5); shows distance concealed knife (7) is projected.
5. Cylinder which screws down over (4) on which its lower edge serves as index to read graduation. It is rotated by milled disc (6) and carries a wire which passes down hollow needle (1) and is connected with concealed knife (7) which it projects.
6. Milled disc which rotates cylinder (5).
7. Watch-spring concealed knife which can be projected 4 mm. and withdrawn by rotating (6).
9. Milled disc which with (3) fits the clamp (119) and prevents any longitudinal displacement of needle.
118. Screw head which serves as handle.
119. Clamp which holds cylinder (2) with moderate friction effected by screw (121); it checks but does not prevent rotation of cylinder.
121. Screw which holds clamp (119) and regulates friction.

The following parts seen in this figure are also shown in Plate XVI, 114, and have the same numbers.

93. Inner sheath.
95. Head of pinion by which bed is moved in inner sheath.
96. Screw by which inner sheath is locked in outer sheath.
97. Stop.
99. Tension screw to close jaws of stop.
100. Shunt for bringing stop into circuit.
101. Terminal of lead for connecting stop.
110. Scale of inclined needle.
113, 114. Adjustable index for scales of rectilinear needle.
115. Screw to regulate friction of pinion (95).

III. Orthotome

Numbers as in II.

8. Wire which is connected with concealed knife (7).

IV. Mussen's Spherotome

Numbers as in II.

V. Fine Steel Tube

For introducing drugs, etc.

1. Tube.
2. Cylinder held by clamp (119).
10. Funnel.
11. Rod which fits tube (1).

PLATE XVI A

Design for improved bed for cutting needles, especially fine hypodermic needles from which a steel wire can be projected at a right-angle for 2 or 3 mm.

1. *Bed* which is made of brass and fits the inner sheath (Pl. XIV, 93) of the needle-holder. The rack shown on the edge of the bed is engaged by the pinion (95) attached to the inner sheath and serves to project or withdraw the needle.
2. *Adjustable index* for reading the scale of the needle in the rectilinear instrument.
3. *Indicator scale* for inclined needle.
4. *Screw head* which serves as a handle for introducing or removing bed (1) from inner sheath (93).
5. *Outer Cradle.*
6. *Inner Cradle.*

7, 8. *Upper and lower end plates* of outer cradle.

9, 10. *Upper and lower end plates* of inner cradle.

11. *Rectangular center rod* pivoted in the slots of the upper and lower end plates of outer cradle. It traverses the inner cradle from one end plate to the other and is fixed to both. It therefore supports the inner cradle and when rotated on its pivots effects a rotation of the inner in the outer cradle. The center rod has a circular groove at the point where it engages the slot (13) of the upper end plate (7) to facilitate rotation of the rod and prevent its longitudinal displacement.
12. *Cross handle* attached to end of center rod. The four arms, corresponding to the four surfaces of the rod and inner cradle, indicate quarter turns of the latter.
13. *Slot* in upper end plate of outer cradle. It engages the circular groove in the center rod (11).
14. *Spring bar* which holds center rod (11) in the slot (13) of upper end plate.
15. *Spring* to hold (14).
16. *Screw thread* which occupies a few millimeters of the center rod (11) and on which the milled disc (17) moves the clamp (18).

17. *Milled disc* which travels a few millimeters up and down (16) carrying the clamp (18) and wire (19) with it.
18. *Sliding clamp* in which the end of the wire (19) is fixed. A circular groove at the upper end of the clamp is engaged by a corresponding feathered edge on the lower surface of the milled disc (17). Rotation of the disc does not turn the clamp, owing to the square section of the center rod on which it slides, but causes it to travel up and down the center rod as far as the milled disc (17) moves on the screw (16).
19. *Wire* which passes down hollow needle (29) and is continuous with watch-spring knife (19) which it causes to project from the slot near the end of the needle.
20. *Slot in clamp* (18) to hold wire (19).
21. *Ring* which screws over tapered nozzle (22) of sliding clamp (18) causing the slot (20) to grip the wire (19).
22. *Tapered end of sliding clamp* provided with screw thread for ring (21) which makes a vice of slot (20) to hold wire (19).
23. *Index of millimeter scale* (24) showing length of wire or knife (19) projected from needle (29).
24. *Millimeter scale,* adjustable.
25. *Hollow tapered nozzle* screwed to lower end plate (10) of inner cradle (6) which engages the socket (26) of the needle; nozzle of different sizes for different needles can be employed and interchanged.
26. *Socket of needle.*
27. *Stud* which engages slot (28) in socket (26) of needle prevents displacement and ensures the projection of the wire or knife in the same direction.
28. *Slot in socket (26) of needle* for stud (27).
29. *Shaft of needle.*
30. *Orifice* from which knife or wire (19) is projected from needle.
31. *Slot in lower end plate* (8) to receive the needle which thus forms the lower pivot on which the inner cradle rotates.
32. *Cross bar* with V-shaped notch on posterior edge to engage the needle (29) and hold it in slot (31).

PLATE XVII.—DRAWINGS OF THREE CUTTING NEEDLES

The three following needles all fit the same bed as (II).

VI. Vertical Cyclotome

For making circular or disc-shaped incisions with a sheathed knife in a plane parallel to the axis of the needle.

III. Orthotome

For making small incisions with concealed knife in the same direction as the needle and parallel to it.

IV. Mussen's Spherotome

For cutting small spheroids with concealed knife.
These needles have been explained (Chaps. I and IV).

PLATES XVIII, XIX, XX, XXI

These four plates show the instrument with a cat's head in position and the needle applied in the first, sixth and seventh positions.

The parts have not been numbered, as they have all been described in previous plates.

PLATES XXII, XXIII, XXIV.—THE NEEDLE-GAUGE

These three plates illustrate the needle-gauge which was used with the rectilinear machine originally and which will meet the requirements of those who have that machine, but have not procured the drilling and gauging cage (Pl. XXXIV). The gauge shown in these plates was constructed before the three diameters of the cage had been made identical, so it is provided with an adjustable index and a scale to set it and the figures for the three diameters of the cage are engraved on one of the feet (132). In future the adjustable index and extra scale will not be required. The index (142) will be at zero on scale (135) when the point of the needle or cap (138) is at the zero plane perpendicular to the needle. In all other respects the application of the gauge will be the same as that shown in the plates. In Plates XXIII, XXIV, the gauge is shown applied to the cage for measuring the vertical diameter of the head. In Plate XXIII the adjustable index (139) is at zero on the scale (135), the index (142) having been brought to 52 on the scale (134). This being the figure engraved at (132) for vertical measurement, the point of the needle is seen at the interaural line. (Pl. XXIV) shows the gauge applied to the head in the cage, the needle penetrating the integuments is in contact with the surface of the cranium and the adjustable index reads 30, showing that in the frontal zero plane, in the mid-sagittal line, the distance from the interaural line to the vertex is 30 mm. in this head.

The cylindrical needle gauge (Pl. XXXIV, 26), which is used with the drilling and gauging cage (Pl. XXXIV) and which fits the same slots as the drill guides (7 and 8) is applied in the same way. When the point of the needle is at the zero plane to which it is perpendicular the index reads zero on its scale, and when the point of the needle is in contact with the cranium, the scale shows the number of millimeters between the zero plane and the point of contact, *i. e.*, the required dimension.

Numbers on cage and head-vice as before (see Pls. VI and X).

131. Base bar.
132. Feet. Right and left.
133. Slide block which travels on (131).
134. Millimeter scale for setting adjustable index (139).
135. Scale for measuring depth of needle.
136. Graduated gauge ending in needle (137) and cap (138). (Figures placed on screw for cap.)
137. Measuring needle, the point of which must be flush with cap (138).
138. Cap which covers needle. When screwed home the point is level with that of the needle and measurements can be reckoned from either.
139. Adjustable index set at zero when the index (142) is at the number on the scale (134) required for the dimension to be measured and engraved at (132). Not required in future.
141. Screw to fix adjustable index (139).
142. Index of slide block (133).
143. Screw to fix slide block (133).

PLATES XXV-XXIX.—INDICATORS

The plates illustrate the two- and three-dimensioned indicators with an arrangement of adjustable gratings for making corrections for size.

The pattern with a ruled card described (Chap. III) has not been constructed, but by comparing the description with these plates the nature of the modification will be evident. When the two-dimensioned indicator was constructed, some difficulty was experienced in making gratings of which the spaces between the threads were rather less than 1 mm. The purpose of the instrument is served equally well if it is enlarged so that in every part as well as the gratings nominal millimeters actually measure two. This makes the instrument inconveniently large if the gratings represent a whole lamella, but as the objective point must lie in one of the quadrants formed by the crossed zero lines of a lamella, it is sufficient if that quadrant only is represented. To represent any quadrant in any lamella in three dimensions the position of the instrument and of the zero lines must be variable; the bars, therefore, which define the zero lines are adjustable and it will be found that by changing the position of the instrument and adjusting the bars, any quadrant can be represented. In future it will be more convenient to make the gratings with spaces of only 1 mm. and representing a whole lamella, the zero lines will then be constant and the adjustable zero bars unnecessary. The plan has generally been followed of illustrating instruments which have been constructed and used and there is some advantage in showing alternative methods which are practicable even if they are not adopted.

PLATE XXV.—ADJUSTABLE GRATINGS FOR TWO-DIMENSIONED INDICATOR

The gratings are formed of silk threads stretched between opposing pairs of sway bars. The threads are in groups of five, alternately black and white. The spaces between the threads are set to measure 2 mm., or more, or less, by inclination of the sway bars (3, 3) (4, 4), which can be fixed at any point by a quadrant and screw (5, 6). The threads pass round small pegs arranged at equal distances on the bars. Each pair of bars is kept taut by a spring and tension screw (7, 8).

1. Vertical threads of grating.
2. Transverse threads of grating.

3, 3. *Pivoted* sway bars for vertical threads.

4, 4. *Pivoted* sway bars for transverse threads.

5. Quadrant with screw for fixing vertical pair of sway bars.
6. Quadrant with screw for fixing transverse pair of sway bars.
7. Spring and tension screw for vertical threads. See Pl. XXVI.
8. Spring and tension screw for transverse threads.

9, 9. Screw nuts which receive and fix sliding plates of frame of indicator (Pl. XXVI, 10).

PLATE XXVI.—THE TWO-DIMENSIONED INDICATOR (COMPLETE)

The various parts of the grating already shown (Pl. XXV) can be seen beneath the frame which carries the quadrant and needle, zero bars and scales. For convenience, the whole instrument and all the scales are enlarged in the proportion of 2: 1. Nominal millimeters, therefore, measure 2 mm., but, as the enlargement is proportional, the scales in the indicator correspond with those of the stereotaxic instrument, though in the latter the scales are in actual millimeters. For the purposes of description the indicator is assumed to be in the first position of the needle in the stereotaxic instrument, *i. e.*, the quadrant above, facing forwards, the needle inclined in the direction of the right internal capsule downwards and to the left (the observer's right).

10. Frame.
11. Plates by which the frame is held on the board by the screw nuts (9, 9). When these are relaxed, the whole frame can slide on the plates.
12. First zero bar, representing one of the zero planes. It always represents the zero plane parallel to the traversing stage in the stereotaxic instrument, perpendicular to the rectilinear needle, and as that is a constant, the distance from this bar to the pivot of the needle (21) is a constant in the indicator, and if the bar is moved, the frame and the needle move with it.
13. Second zero bar (a).

14. Second zero bar (*b*).

The objective point in any quadrant of a lamella is always measured from two zero planes represented by lines in the chart. The first zero bar (12) always represents one of them. To allow for different positions it is necessary to have two zero bars in the indicator to represent the other; but the two are never used together, and whichever one is employed it always represents the second zero plane, so they are both called second zero bars. They cannot be distinguished as right and left, so the letters *a* and *b* are adopted for that purpose. Both these bars are movable.

15. Is placed on the quadrant, it also indicates the position of the carrier on which the quadrant is fixed and which is not seen; the quadrant slides on the guide (24) and is fixed by the screw (19).
16. Index for reading quadrant scale (18).
17. Sheath in which needle (20) slides.
18. Quadrant scale.
19. Screw which fixes carrier on guide (24).
20. Finder needle.
21. Pivot. The pivot itself is not seen, the figure is over it and points to the index for reading scale on needle which shows length from point to pivot in millimeters.
22. Pointer at the end of needle.
23. Screw to fix needle in sheath.
24. Transverse guide. Corresponds to transverse guides in stage of stereotaxic instrument.
25. Upper millimeter scale belonging to second zero bar (*a*) (13) and which moves with it. It is necessary for the two zero bars in use to be moved to coincide with one of the threads of the grating, because the objective is found by counting the divisions of the grating from it. It is, therefore, necessary that the scale which measures the distance of the pivot of the needle (21) from the zero bar, should move with the latter; so the scales of both second zero bars move with them. When the first zero bar (12) is moved, the pivot and frame move with it as explained (12).
26. Lower millimeter scale belonging to second zero bar (*b*) (14) and moving with it.
27. Index which reads scale of second zero bar (*a*) (13) and gives distance of pivot (21) from zero bar (*a*).
28. Finder needle and its scale; this needle hides index which reads scale of second zero bar (*b*) (14).
29. Pins to fix first zero bar (12). They can be taken out and the bar removed.
30. Screw to fix needle in quadrant at required angle.

PLATES XXVII-XXIX.—THE THREE-DIMENSIONED INDICATOR

1. Steel base plate.
2. Right and left anterior columns with slots for feet of cage or equatorial corresponding to similar slots (42) in the head-vice (Pl. VI).
3. Posterior ditto.
4. Longitudinal horizontal grating for transverse measurement. It is composed of silk threads about 1 mm. apart, the spaces being variable by inclination of the sway bars (5).
5. Sway bars of longitudinal grating (4).
6. Quadrant with scale to adjust longitudinal grating (4).
7. Screw to fix quadrant (6).
8. Transverse grating, prefrontal.

9, 9. Sway bars of (8).

10. Quadrant and scale for adjusting transverse grating (8).
11. Screw to fix (10).
12. Transverse grating, postfrontal.

13, 13. Sway bars of (12).

14. Quadrant and scale for adjusting transverse grating (12).
15. Screw to fix (14).
16. Vertical grating.

17, 17. Screws to fix vertical grating to plate (1).

18. Bridge which supports horizontal radius bar (23).
19. Rotatory and sliding joint of horizontal radius bar (23).
20. Screw to fix joint (19). The figure is placed over the pivot of the rotatory joint.
21. Graduated quadrant for adjusting rotatory joint (19).
22. Pinion for racking horizontal radius bar (23) in joint (19).
23. Horizontal radius bar.
24. Vertical index needle.
25. Sliding joint and fixing screw of vertical index needle (24).
26. Pinion for racking vertical radius bar (27) in joint (30).
27. Vertical radius bar.
28. Sliding joint and screw of horizontal index needle (29).
29. Horizontal index needle.
30. Rotatory and sliding joint of vertical radius bar (27).
31. Screw to fix joint (30).
32. Sway bars of vertical grating.
33. Quadrant of vertical grating.
34. Screw to fix quadrant (33). (*N. B.*—The quadrant of the vertical grating was not completed when the other plates were prepared.)

White threads will be noticed at intervals in all the gratings; they represent all the standard dimensions in the cat and rhesus and facilitate direct measurement whether this is adopted as the sole method or to verify measurements by the quadrant scales.

In the longitudinal horizontal grating the central white thread represents the median longitudinal plane. Of the pairs of threads

parallel to it the inner pair represent the standard transverse diameter of the cranium of the cat, the outer the same dimension of the rhesus.

In the transverse horizontal grating a white thread at the junction of the anterior and posterior gratings represents the inter-aural line, and four other threads the corresponding anterior and posterior dimensions in the same standard animals.

Three white threads in the vertical gratings represent from below upwards the basal horizontal plane and the standard vertical measurement of the cranium in the cat and rhesus, respectively.

PLATE XXVIII A

A method of identifying and representing the index point.

1. Square rod sliding vertically without rotating in the slot at the end of the horizontal radius bar (23) and fixed by a screw. It is reversible.

2, 3. Horizontal arms carrying rotating crosses, the pivots of which represent index points (4, 4′; 5, 5′).

4, 5. Index points. Upper and lower. Numbers point to upper ends of tubes.

4′, 5′. Lower ends of tubes which may serve as index points.

6, 7. Arms of crosses.

8. Needle which passes vertically through the pivots or naves of the crosses and identifies a marked mesh in the horizontal grating.

PLATE XXIX.—THE EQUATORIAL APPLIED TO INDICATOR

Shown in position mounted on the indicator and carrying the needle-holder (Pl. XIV) and operating needle (98), the point of which is in contact with that of the index needle (24) of the indicator. Numbers in the indicator as before.

35. Inner ring of turntable fixed by four feet (37, 38) which are engaged in the slots of columns of the indicator (2 and 3).

36. Outer ring of turntable which rotates on (35) and is fixed by screw (39).

37. Anterior feet of inner ring (35).

38. Posterior ditto.

39. Screw to fix turntable.

40. Arch which passes across the outer ring and conveys the needle-carrier (44) which traverses it by a sliding movement controlled by a fixing screw (45).

41. Rectilinear guides on which the feet of arch slide, carrying the arch and needle-holder across the rings of the turntable at right-angles to the direction of the arch.

42. Feet of the arch which slide on (41).
43. Screw for locking sliding movement of arch.
44. Carrier on which is pivoted the outer sheath (72) of needle-holder. It traverses the arch (40) and is fixed at any required point by the screw (45).
45. Screw which fixes the carrier (44) and also the quadrant of the outer sheath (47).
46. Screw which locks the inclination of the outer sheath (72) upon the carrier (44).
47. Quadrant connecting carrier (44) with outer sheath (72). It regulates the inclination of the outer sheath and needle and fixes both carrier and quadrant.
48. Screw which locks the inclined movement of the outer sheath (72) in quadrant (47).

PLATE XXX.—THE EQUATORIAL APPLIED TO HEAD-VICE FRONT VIEW

When the equatorial is applied in this way to the head-vice which contains a head, the latter is encircled by the inner ring about the level of the mid-horizontal plane. It will be seen that this affords the needle a great variety of positions and directions.

Numbers of equatorial and head-vice as in Plates VI and XXIX.

PLATES XXXI, XXXII, XXXIII AND XXXIV.—DRILLING AND GAUGING

These three plates show the method of drilling in three diameters first adopted in the rectilinear machine and which is effected by means of a square frame, one side of which is removable and which can be fitted over the cage in the frontal and horizontal zero planes. The former position is employed for vertical and transverse and the latter for longitudinal drilling. Two of the sides of the frame (2 and 3) carry slide blocks (5 and 6) which are slotted for sliding cylindrical drill guides (7 and 8) which can be pushed into contact with the head and retained in any position by screws (10 and 12). The slide blocks (5 and 6) can also be fixed at any point on the side of the frame to which they are attached by the screws (9 and 11) and the position of the slide blocks is determined by a millimeter scale and an index formed by the chamfered edge of the slide block.

The three punctures usually required for vertical and transverse drilling are all made in the frontal zero plane, so the frame when used for these purposes is retained in the frontal zero plane. For longitudinal drilling the frame, which is now fitted over the cage in the horizontal plane (Pl. XXXII), is brought to the correct

level (shown by millimeter scales on the legs of the cage) by four screws, all numbered (19).

It was obvious that it would be much more convenient to have this frame permanently fixed to a special cage in the frontal zero plane for vertical and transverse drilling, and for longitudinal drilling to have two slide blocks carrying the drill guides attached to two transverse horizontal bars, anterior and posterior, extending between the anterior and posterior legs of the cage on which they can be raised and lowered by slide blocks provided with scales and fixed with screws.

Plate XXXIV shows this instrument. It has the advantage that, by using a cylindrical needle-gauge (26) which fits the slots in the slide blocks, measurements of the cranium can be made with the greatest accuracy. The needle-gauge punctures the integuments and records the dimensions of the surface of the cranium, as already explained, and the guides ensure the accurate direction and position of the needle so that the diameters recorded are always perpendicular to the zero plane they traverse and are always made in the same position, *i. e.*, through the same points, advantages which are essential and can only be secured by the use of such a frame. It is difficult to recognize all these arrangements for drilling and gauging in three diameters in a single photograph of the complete instrument and easier to follow them in the three plates where they are shown separately with the movable frame. When the application of the frame has been recognized in these plates there will be little difficulty in following the slight modifications which have been introduced in the permanent drilling and gauging cage (Pl. XXXIV). In the first three plates the same numbers as have been previously adopted for the various parts of the head-vice and cage * (Pls. VI and X) are applied to the same parts. In Plate XXXIV most of these numbers are omitted; after studying the first three plates the structures will be recognized and to introduce so many numbers in a single illustration would be likely to cause confusion.

Plate XXXI, arrangement of frame for transverse drilling; XXXII, for longitudinal drilling; XXXIII, for vertical drilling; XXXIV, the special drilling and gauging cage.

* The head-vice, cage and stage reappear in many subsequent plates which made it desirable to retain the same numbers for identical parts. But it was not practicable to continue this in the later plates. It is inconvenient to employ nothing but numbers of three figures and further, there is no great advantage in retaining the same numbers in the later plates as they do not reappear like the earlier ones. So, in the later plates when parts of the frame, cage, etc., appear the original numbers are used, but for fresh structures a new series of numbers is employed.

The numbers indicating parts of the head-vice and cage as before; those referring to parts of the drilling apparatus are as follows:

1, 2, 3, 4. The four sides of the frame which is applied to the cage. The side (4) is detachable and fits on to (2 and 3) by joints (13 and 14). The sides (2 and 3) carry slide blocks (5 and 6). The slide blocks are adjusted by millimeter scales and indices and fixed with the screws (9 and 11). They are also perforated with slots to fit the sliding cylindrical drill guides (7 and 8) and the latter are fixed by the screws (10 and 12).

5, 6. Slide blocks for drill guides, attached to sides 2 and 3 of frame.

7, 8. Cylindrical drill guides.

9, 11. Screws to fix (5 and 6).

10, 12. Screws to fix (7 and 8).

13, 14. Joints for fixing detachable side of drilling frame.

15, 16, 17, 18. Clamps for attaching the drilling frame to the ordinary cage of the rectilinear machine.

19. Screws for adjusting the height of the frame in the horizontal position for longitudinal drilling.

32. Needle passed through opposite pairs of drill guides.

In Plates XXXI to XXXIII, except 32, all numbers above 20 are numbers previously applied to parts of the head-vice and cage (see Pls. VI and X) and refer to the same parts in these plates.

Pl. XXXIV.

1, 2, 3, 4. Sides of frame permanently attached to cage for vertical and transverse drilling and gauging.

5, 6. Slide blocks for vertical drill guides or cylindrical needle-gauge.

7, 8. Drill guides shown here in the position for longitudinal drilling and traversed by a needle (32).

9, 11. Screws to fix slide blocks (5 and 6).

10, 12. Screws to fix drill guides (7 and 8) or needle-gauge (26).

13, 14. Joints for attaching removable bar (4) of drilling frame.

15, 16. Anterior and posterior transverse horizontal bars which are raised or lowered by slide blocks (21 and 22) on the anterior and posterior legs of cage and carry slide blocks (17 and 18) perforated for drill guides for longitudinal drilling. The slots also fit the needle-gauge.

17, 18. Slide blocks carrying guides for longitudinal drilling.

19, 20. Screws to fix (17 and 18).

21, 22. Terminal sliding joints of horizontal bars (15 and 16). The joints are raised and lowered on the legs of the cage, adjusted by millimeter scales and fixed with screws.

23. Slide blocks which can be raised and lowered on the sides (2 and 3) of the frame attached to the cage. The blocks are perforated for drill guides for transverse drilling and for needle guage.

24. Screws to fix (23).

25. Screws to fix drill guides (7 and 8) or needle-gauge (26) in blocks (23).
26. Cylindrical needle-gauge.
27. Screw cap of needle-gauge. For measuring the surface of the cranium the needle is made flush with the cap by the screw (28) and the cap is then removed.
28. Screw for projecting or withdrawing needle of gauge and making it flush with the cap.
29, 30. Screws to fix (21 and 22).
31. Needle in slots of blocks for transverse drilling.
32. Needle in slots of blocks for longitudinal drilling.
33. Needle of cylindrical gauge. Projected by screw (28).
34. Depth gauge. For measuring posterior wall of orbit (Chap. VI).
35. Cross bar of gauge (34).

PLATE XXXV

Figure I

Galvanic plug for arresting hæmorrhage from bone after trephining.

1. Expanding copper collar. It fits the trephine hole loosely until it is expanded by drawing up the ivory cone (2).
2. Ivory cone which expands the collar (1).
3. Copper ring grooved on its under surface and packed with moist wool. It rests on the surface of the cranium encircling the trephine hole and by the counter-pressure of the cone and collar exerted through the bridge and screw is kept in firm contact with the bone.
4. Screw which draws ivory plug (2) and expands collar (1).
5. Ivory bridge for maintaining counter-pressure between collar (1) and ring (3), thus making the plug self-retaining.
6. Screw which draws collar (1) up and presses bridge (5) down.
7. Terminal connecting battery lead with collar (1).
8. Lead connected by terminal which is not seen, with copper ring (3).

Figure II

Nickel self-retaining plugs for keeping fine glass or platinum tubes in the brain.

1. Plug which screws into trephine hole.
2. Tube which fits the glass or platinum tube to which it is fixed with a drop of shellac. A small disc at the lower end of this tube fits the hollow plug (1).
3. Glass or platinum tube.
4. Screw perforated for the passage of the glass tube fits the hollow plug (1) and when screwed down holds the nickel tube (2) and the glass tube within it in place, and at the same time projects only slightly above the surface of the bone.

In practice the parts 1, 2, 3, 4 in the position shown are all slipped over a fine pilot needle fixed in the holder, and so introduced into the trephine hole by the stereotaxic mechanism. The pilot and glass needles are directed to the required point in the brain. The plug (1) is screwed into the trephine hole, the tube (2) is then slipped down till the disc rests in the bottom of the hollow plug, when it is sealed to the glass tube with a drop of hot shellac.

Finally the cap (4) is screwed down, leaving the end of the glass tube projecting externally.

Figure III

These trephines fit the handle of a dental engine; they are provided with adjustable stops (2), which are convenient, as the average thickness of bone at any point can be judged approximately from the charts.

The second form is the best, as it will in future be fitted with a small locking screw. If it has not quite penetrated the bone it can be lengthened a turn or two at a time and reintroduced and the crown of bone separated without risk of wounding the dura. As the trephines can be changed very quickly in the handle, it is best to begin with one with a fixed center pin until a groove is cut and then substitute one with a stop but no pin.

PLATE XXXVI.—QUADRANT CALCULATOR

The use of this is explained in Chapter VII.

1. Vertical scale or table.
2. Sector or inclined scale.

STEREOTAXIC INSTRUMENT FOR SPINAL CORD (PLS. XXXVII, XXXVIII AND XXXIX)

A stereotaxic instrument for introducing insulated needles for electrolysis or stimulation of small areas, or tracts in the spinal cord.

PLATE XXXVII

Shows the instrument from the front with the balance gauge in position. The object of the gauge is to set the sheath by the quadrant, so that either the pilot or the insulated needle will be perpendicular to the zero horizontal line, which lies on the surface of the posterior columns of the cord in a transverse section.

PLATE XXXVIII

The same from the right front with the pilot needle in position.

PLATE XXXIX

The same with the insulated needle in position.

1. Cradle.
2–5. Levers with spring back and pinion catches for gripping vertebra.
6. Screw for transverse movement of stage.
7. Screw to fix needle-holder which slides in sheath (23).
8. Quadrant for setting sheath by balance gauge (9).
9. Balance gauge.
10. Millimeter scale for transverse movement of stage effected by screw (6).
11. Pilot needle.
12. Screw for longitudinal movement of needle parallel to axis of spine.
13. Needle-holder.
14. Ivory bed of needle-holder.
15. Clamp for glass tube of insulated needle.
16. Clamp for wire of insulated needle.
17. Terminal for battery wire.
18. Wire and glass tube.
19. Scale for showing distance of point of needle from transverse zero line on surface of posterior columns.
20. Adjustable index for scale (19).
21. Vulcanite stop which is brought into contact with posterior columns of cord.
22. Fine screws for extension of bed and needle measured by scale (19) and adjustable index.
23. Sheath of needle-holder.

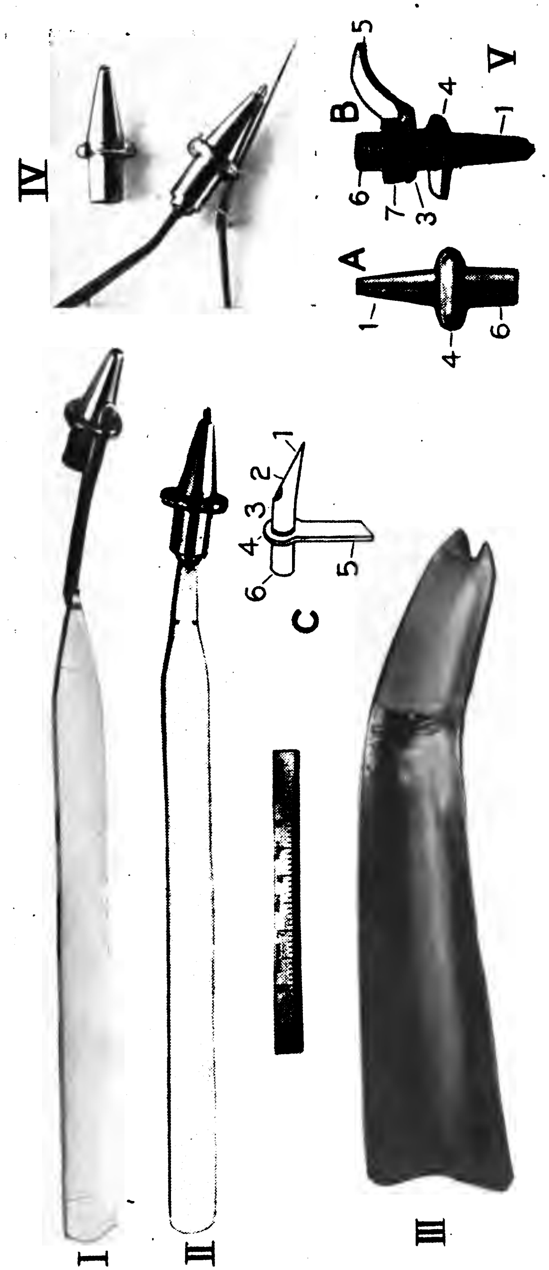


PLATE I.

PLATE II.

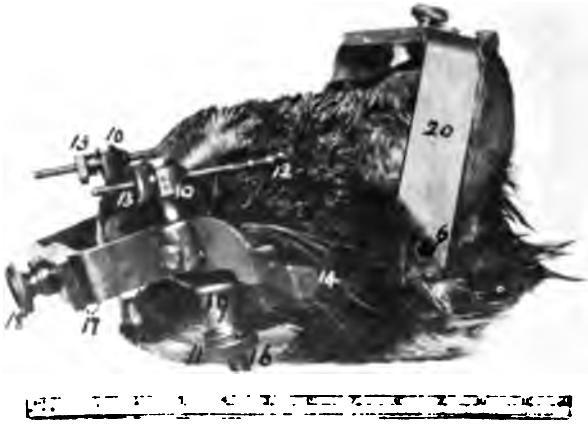


PLATE III.

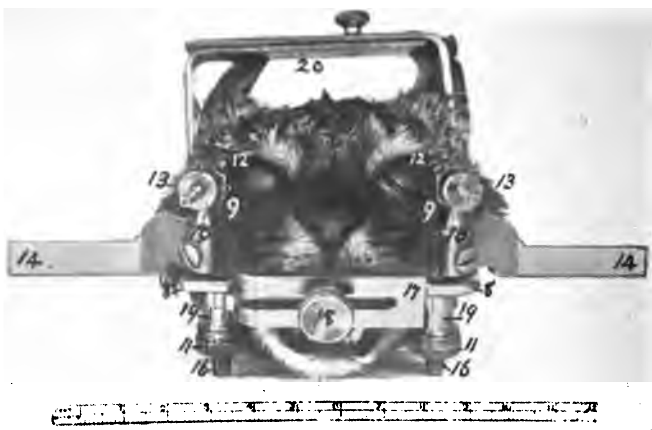


PLATE IV.

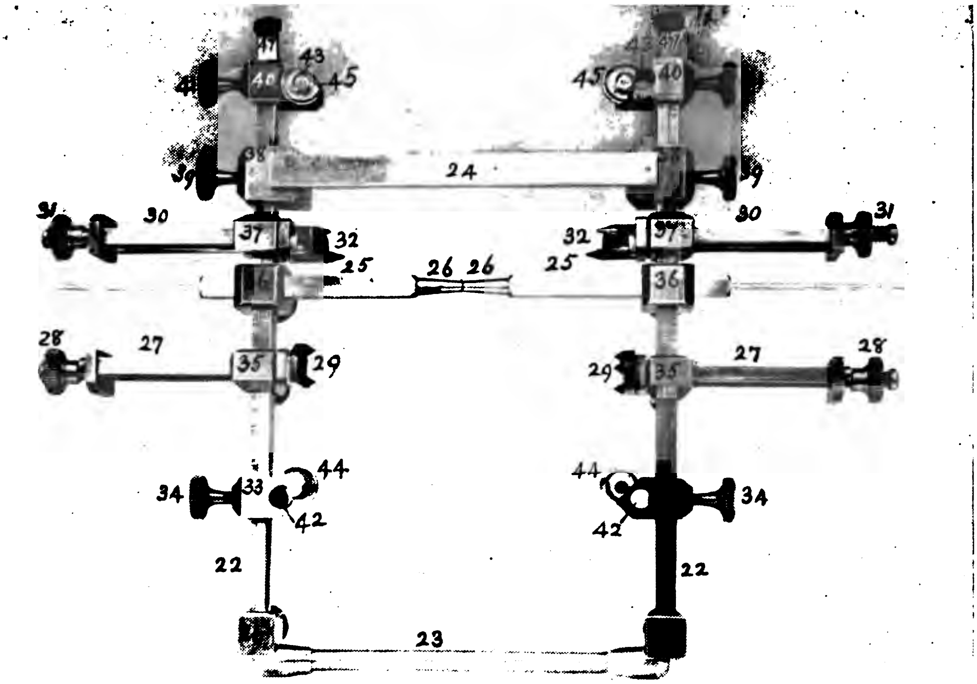


PLATE V.

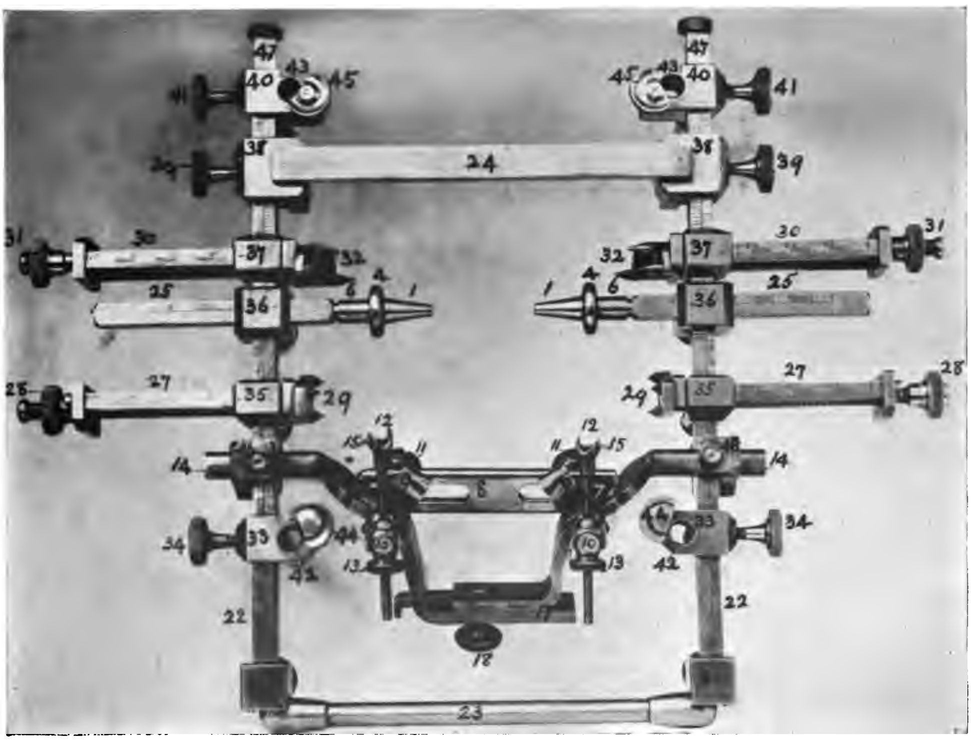


PLATE VI.

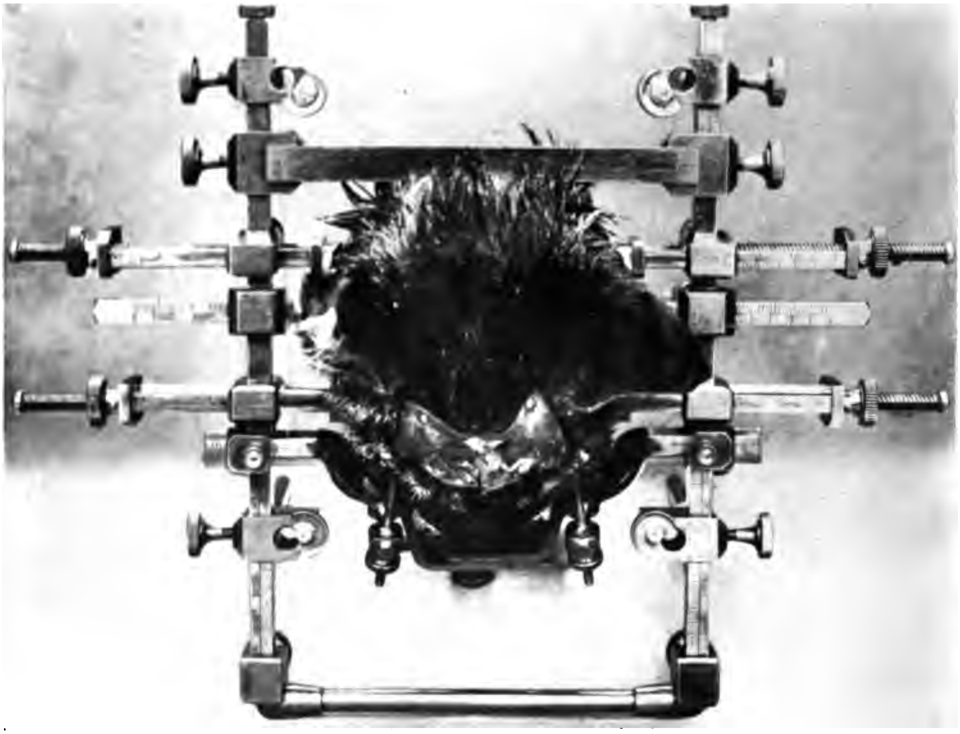


PLATE VII.

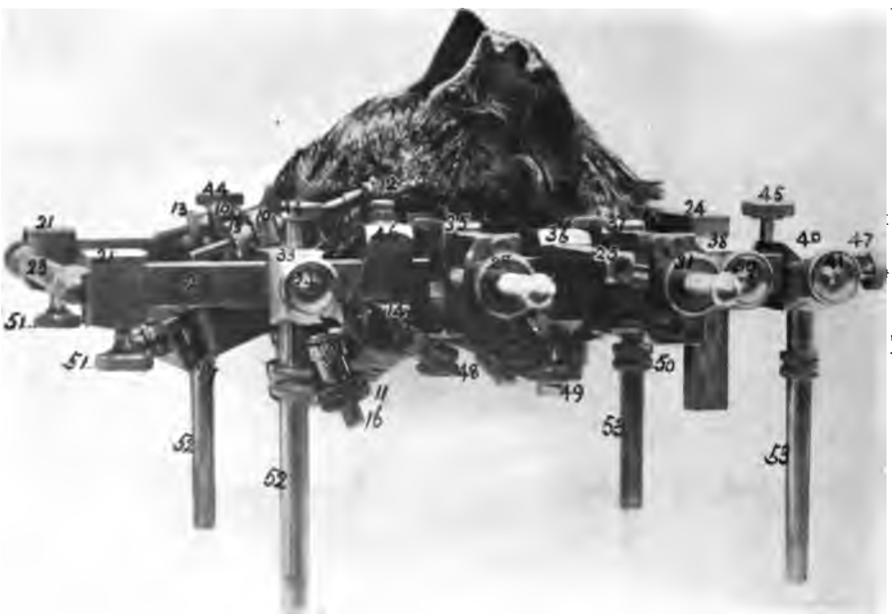


PLATE VIII.

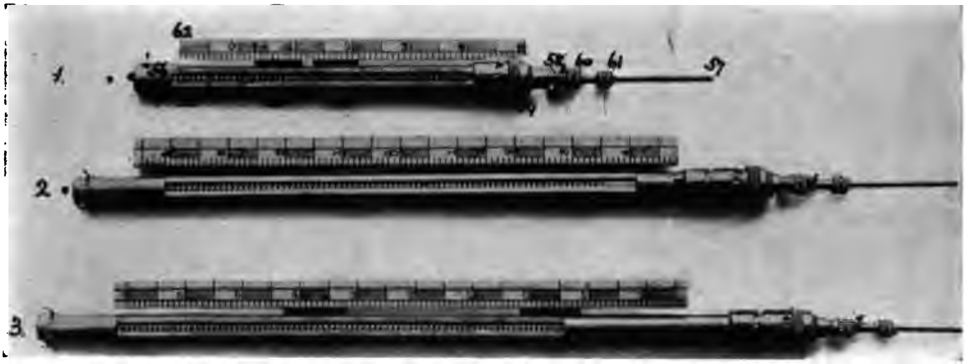


PLATE IX.

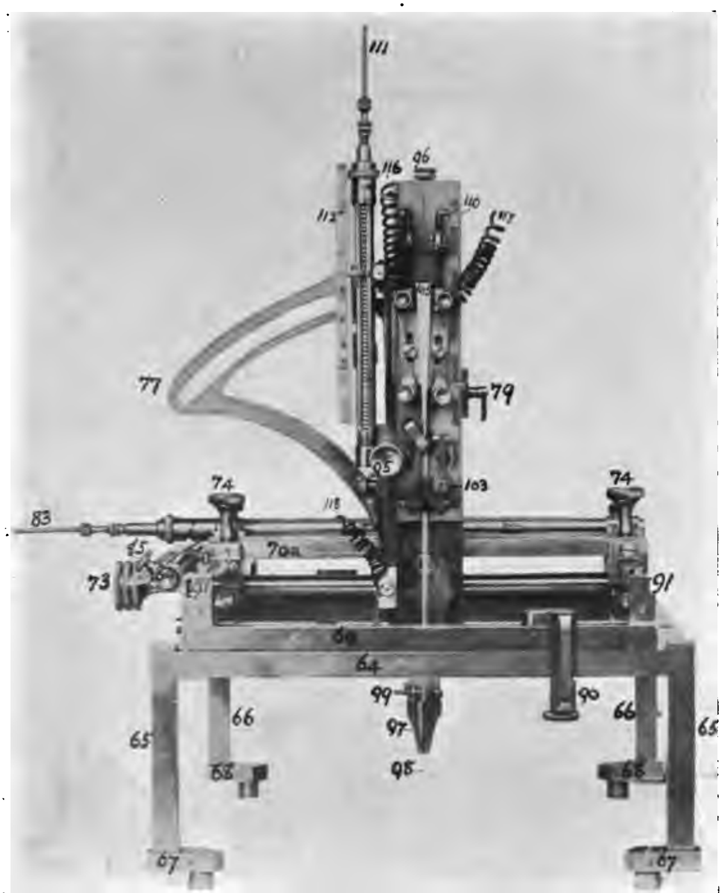


PLATE X.

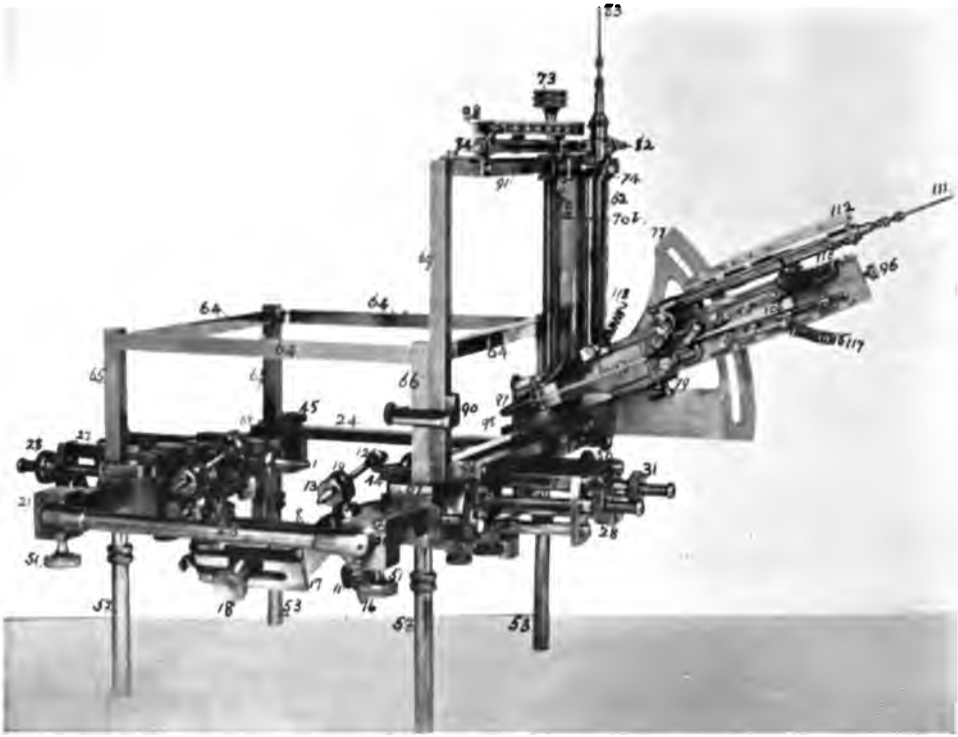
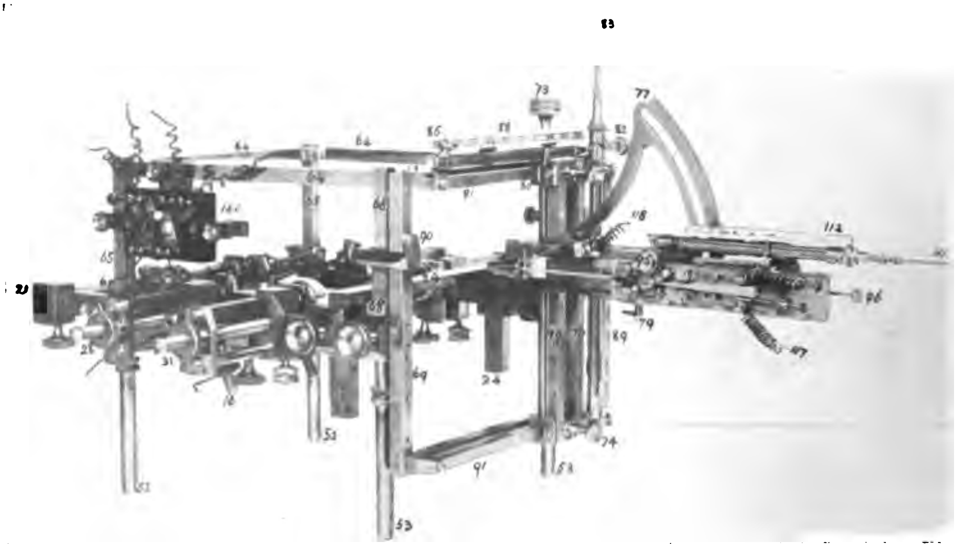


PLATE XI.



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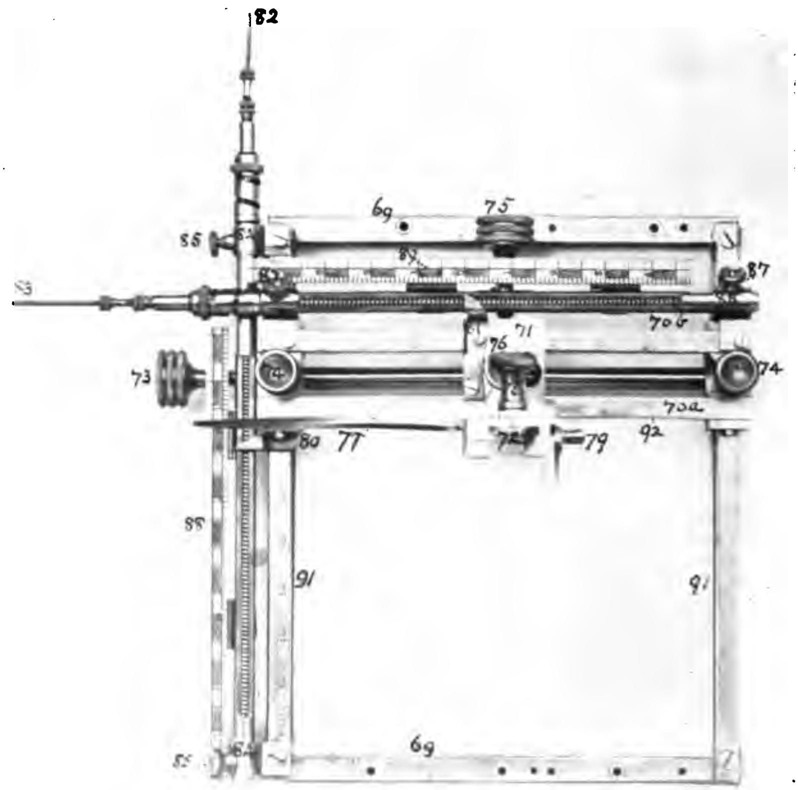


PLATE XIII.

PLATE XIV.

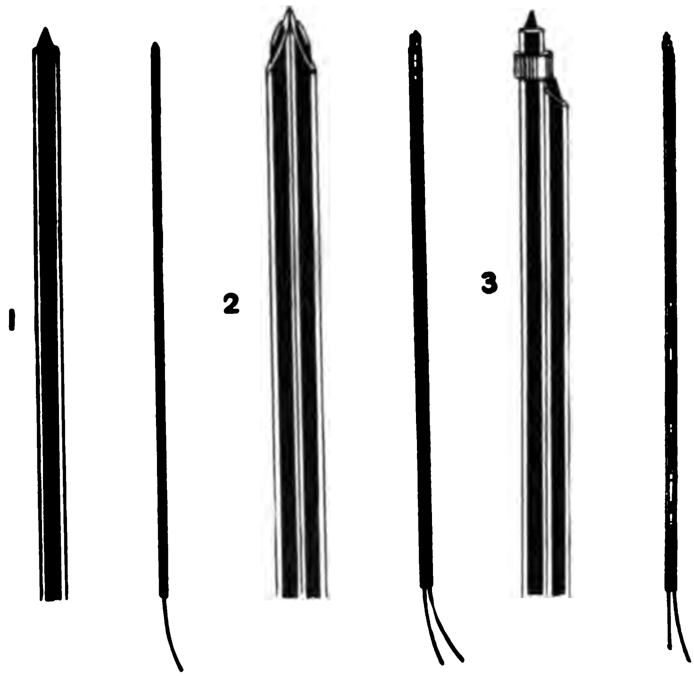


Plate XV.—Platino-iridium needles insulated in glass tubes. 1, single needle; 2, double-barrelled needle; 3, concentric needle. (Actual size and enlarged.)

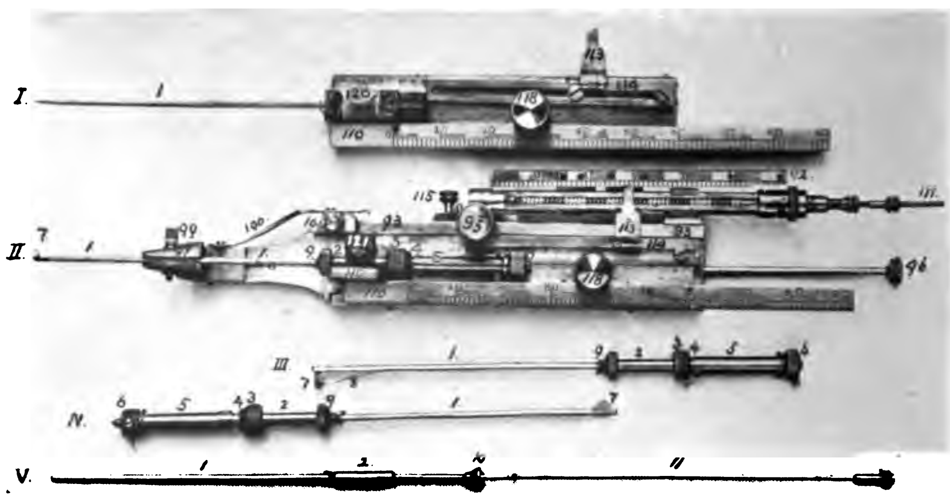


Plate XVI.

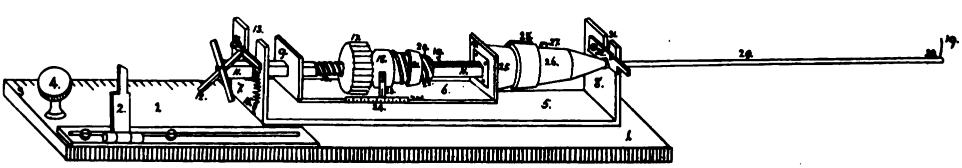
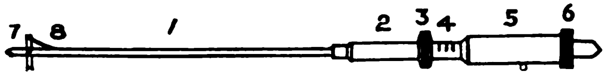
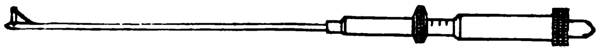


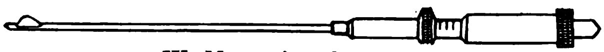
Plate XVI A.



VI. Vertical cyclotome.



III. Orthotome.



IV. Mussen's sphereotome.

PLATE XVII.

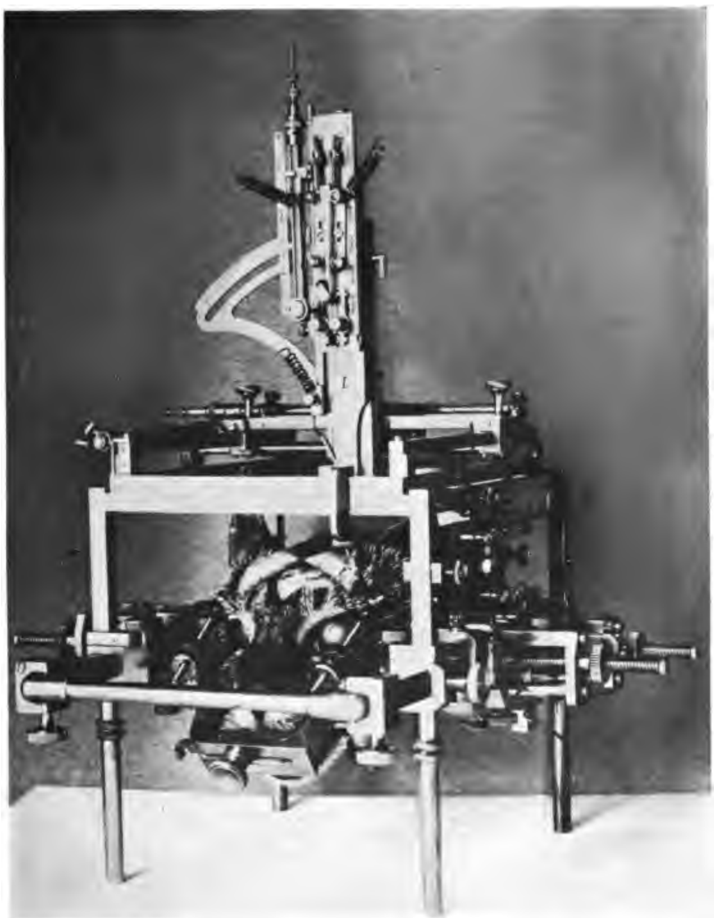


PLATE XVIII.

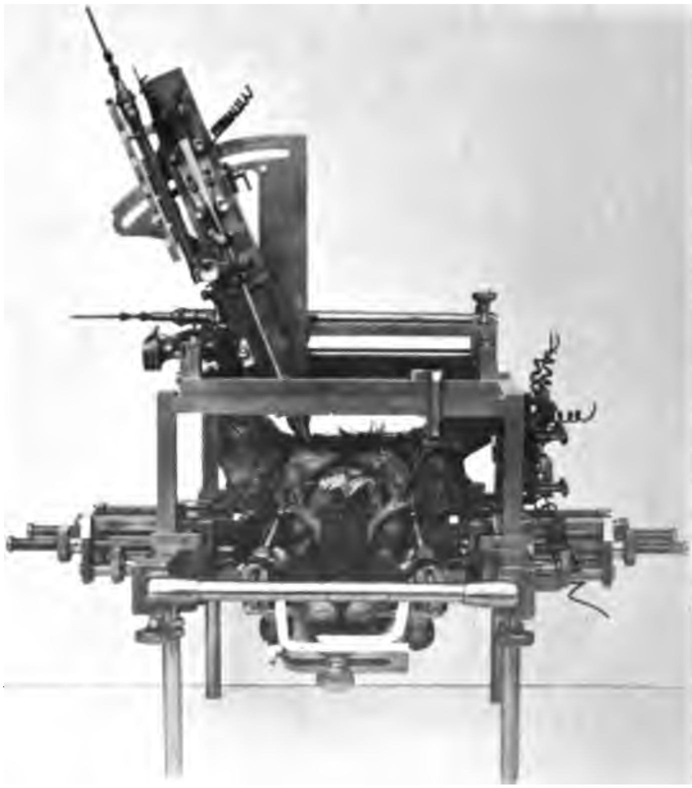


PLATE XIX.

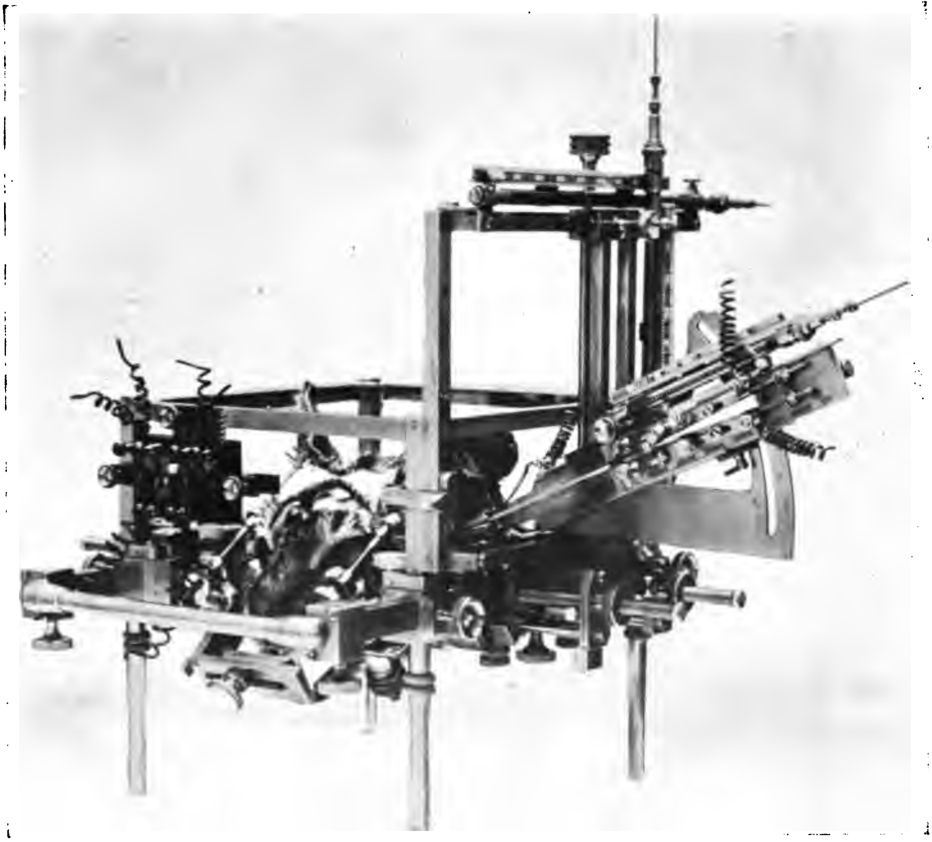


PLATE XX.

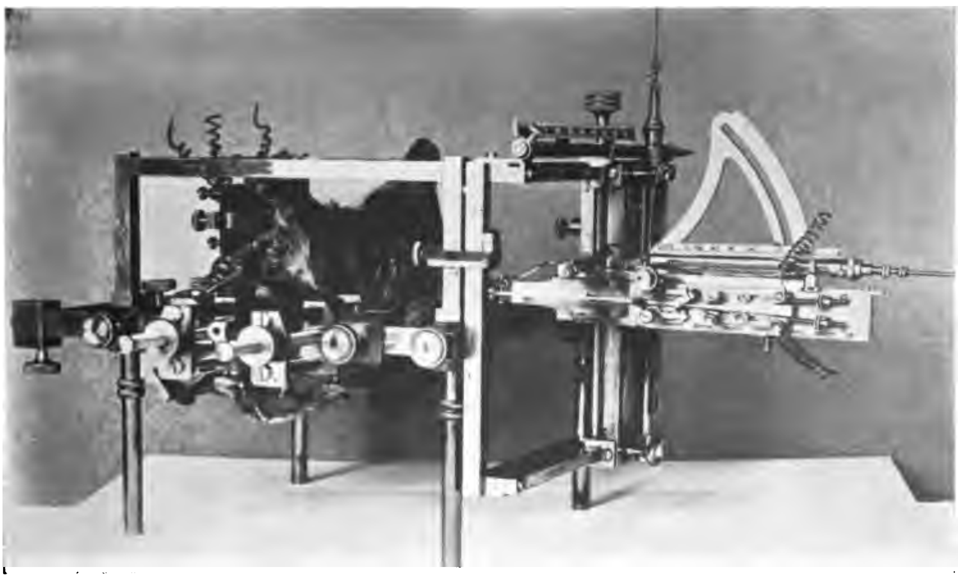


PLATE XXI.

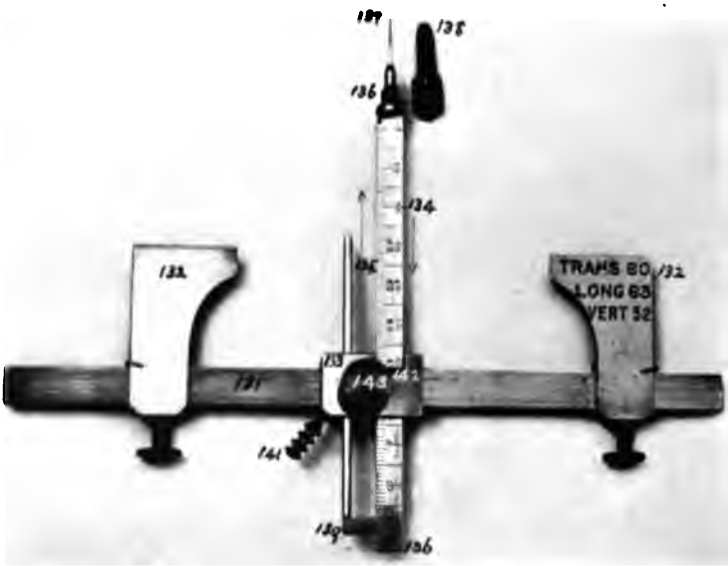


PLATE XXII.

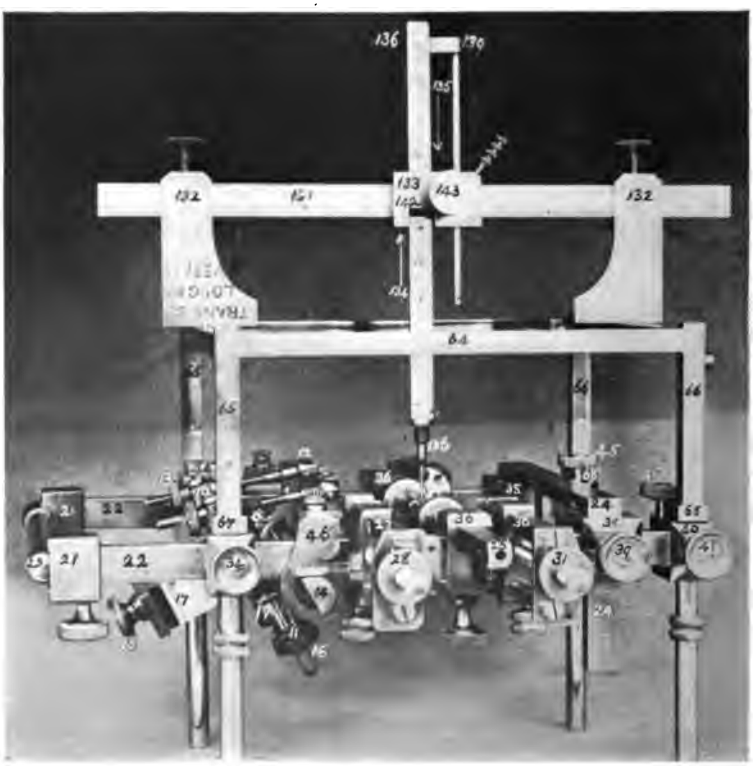


PLATE XXIII.

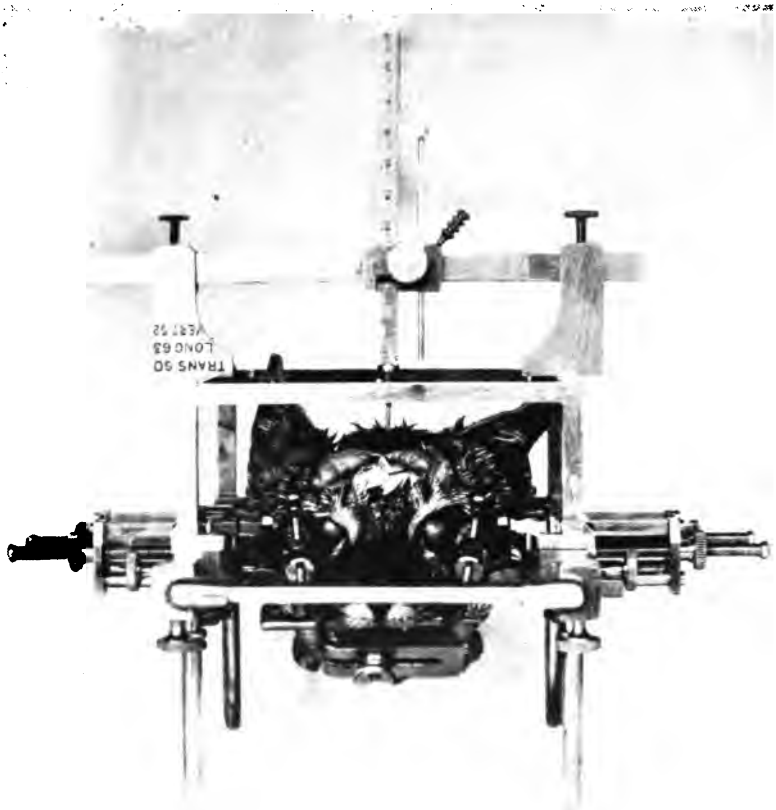


PLATE XXIV.

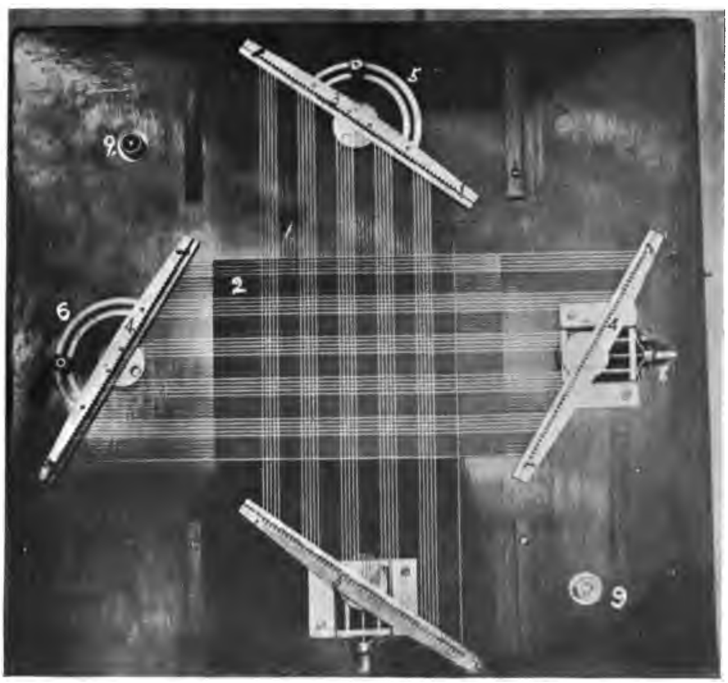


PLATE XXV.

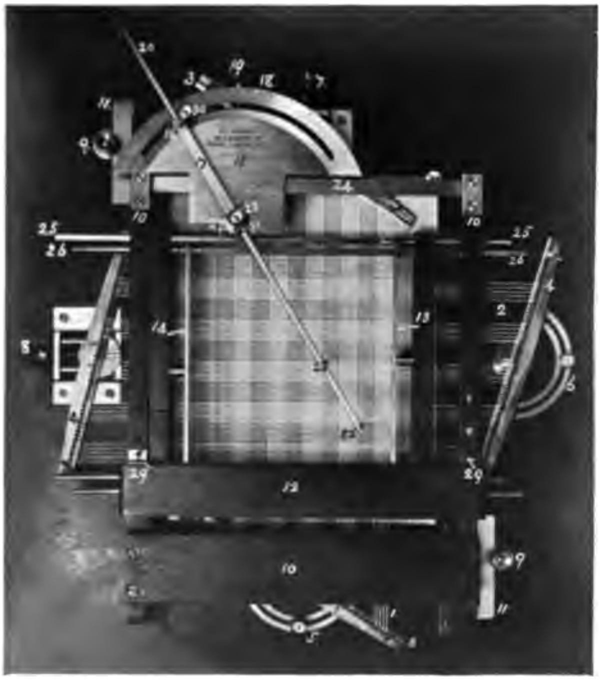


Plate XXVI.

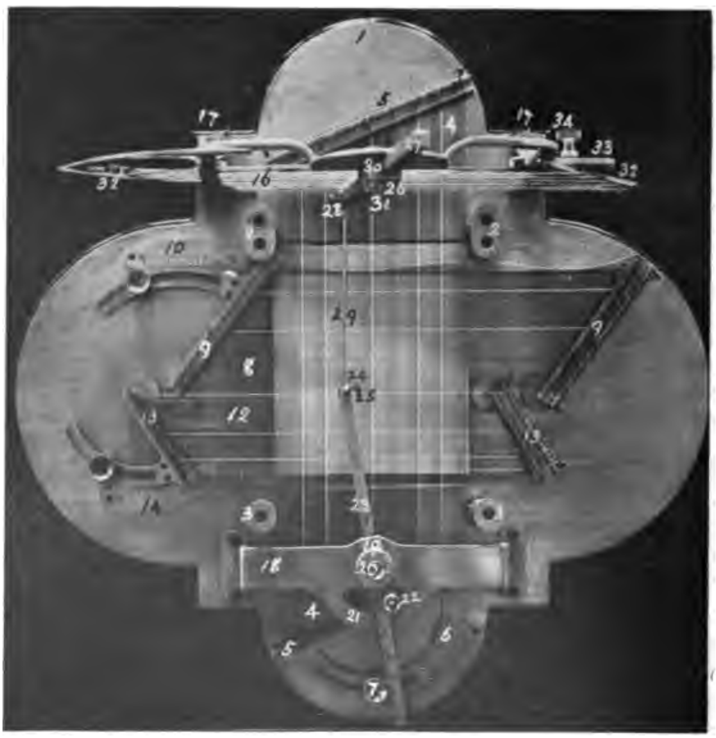


Plate XXVII.

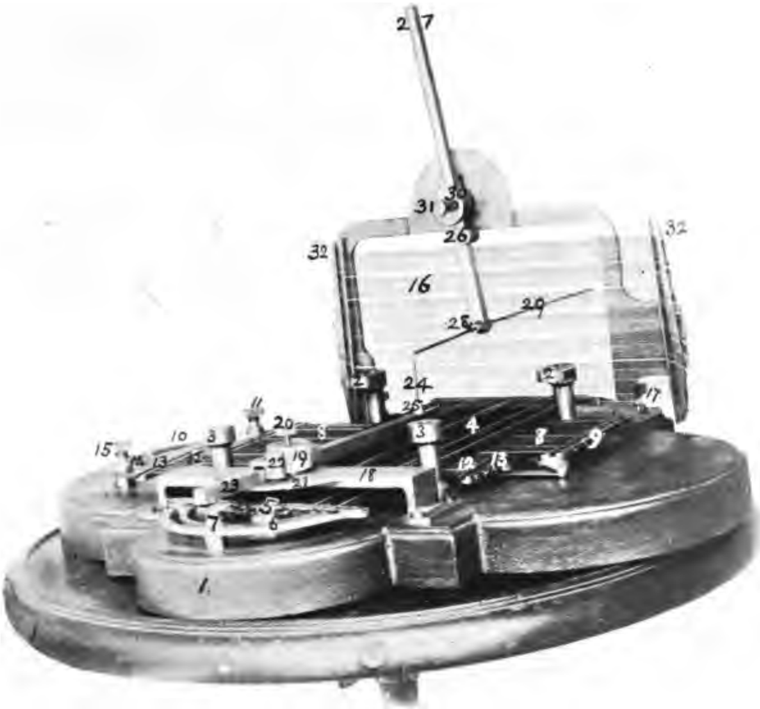


PLATE XXVIII.

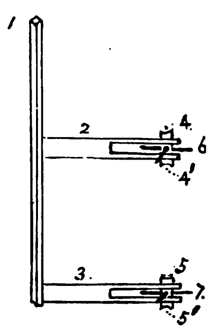


PLATE XXVIII A.
Method of identifying index point.

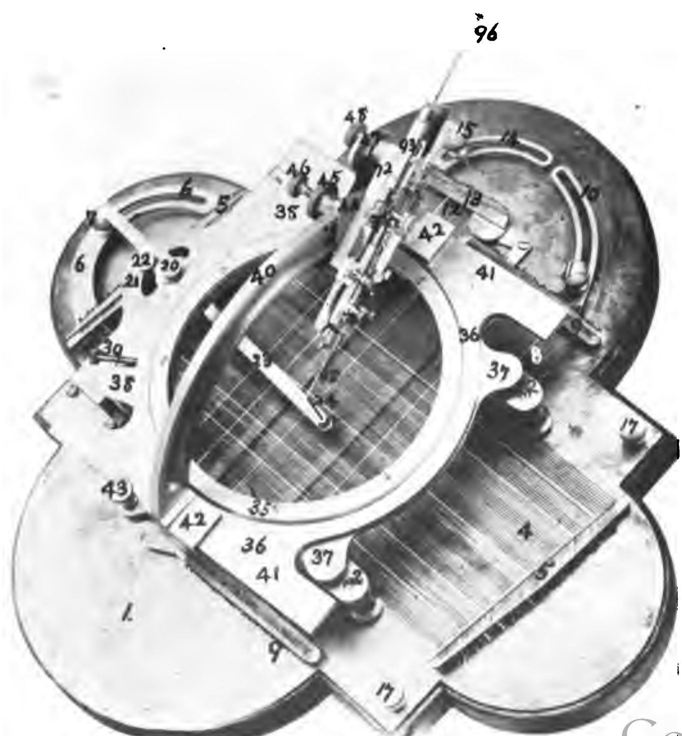


PLATE XXIX.

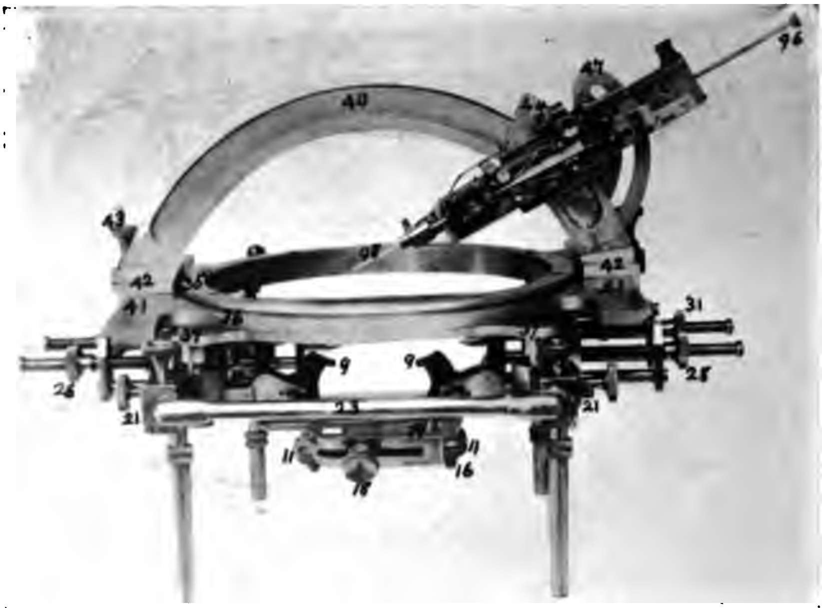


PLATE XXX.

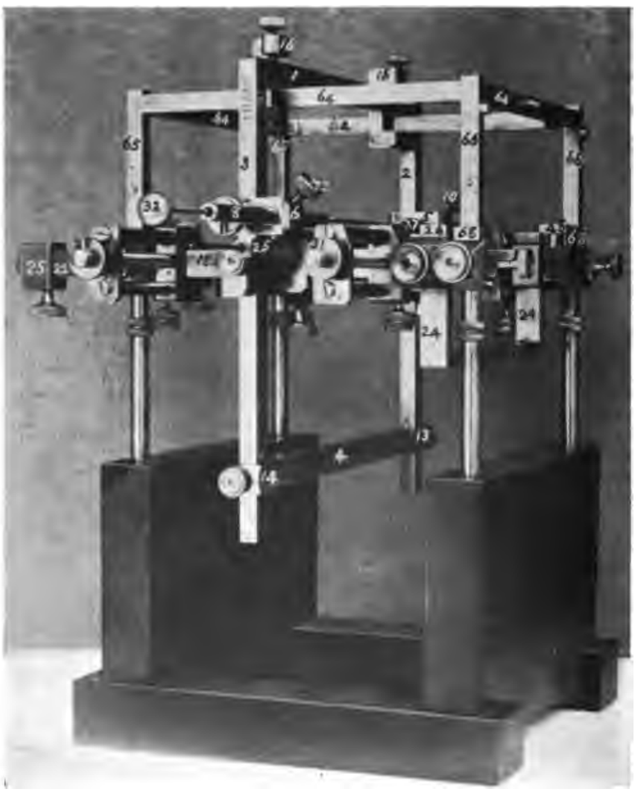


PLATE XXXI.

PLATE XXXII.

PLATE XXXIII.

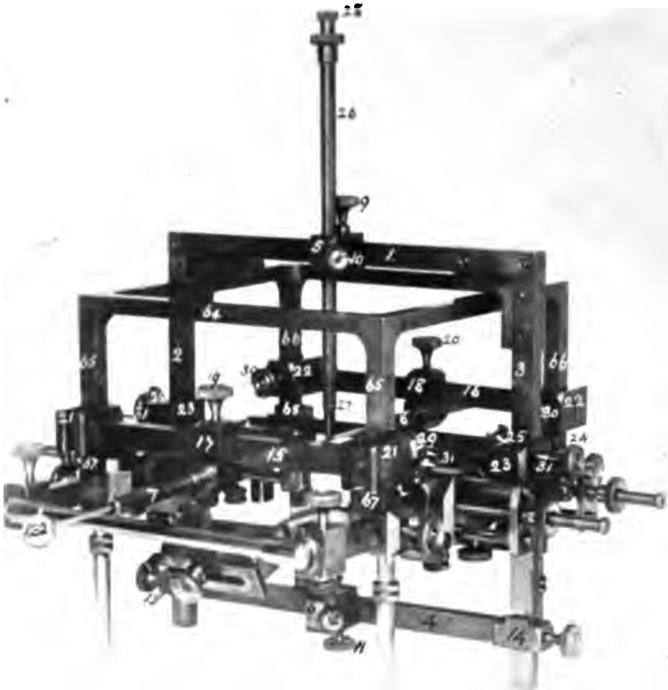


PLATE XXXIV.

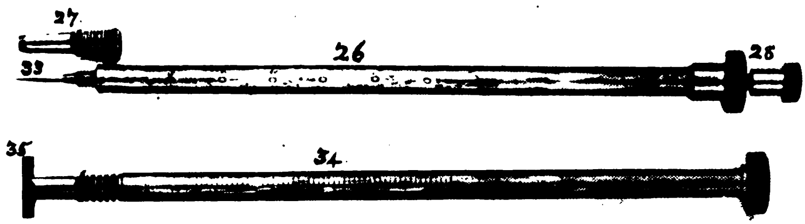


PLATE XXXIV A.

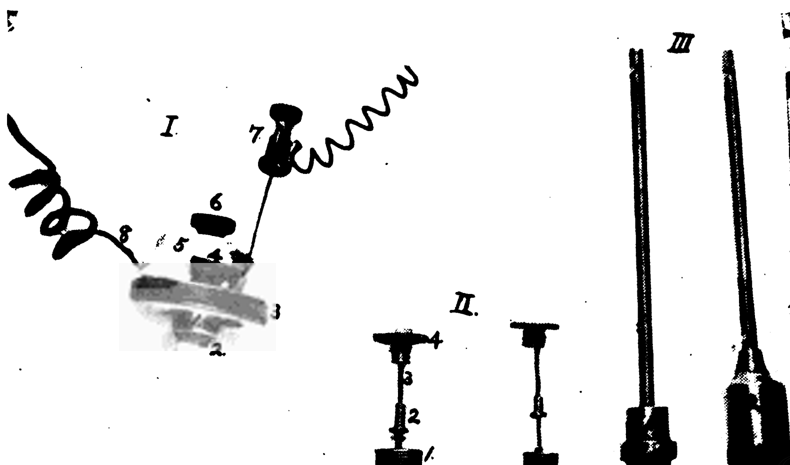


PLATE XXXV.

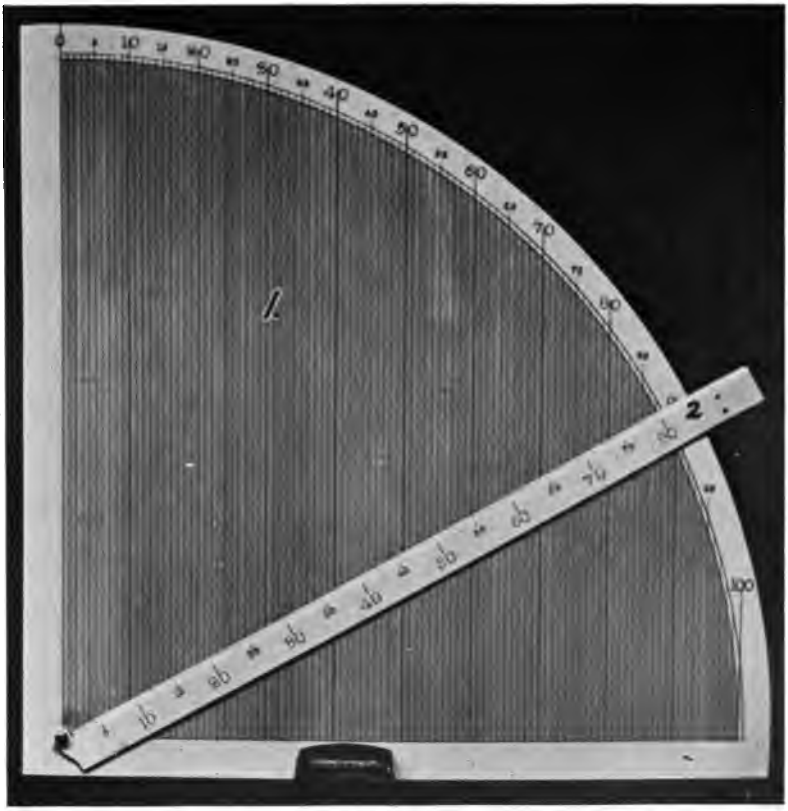


PLATE XXXVI.

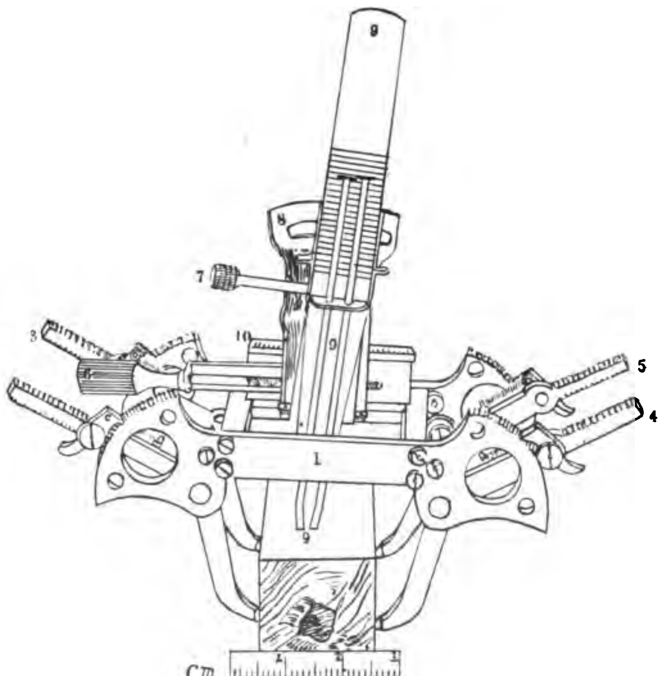


PLATE XXXVII.

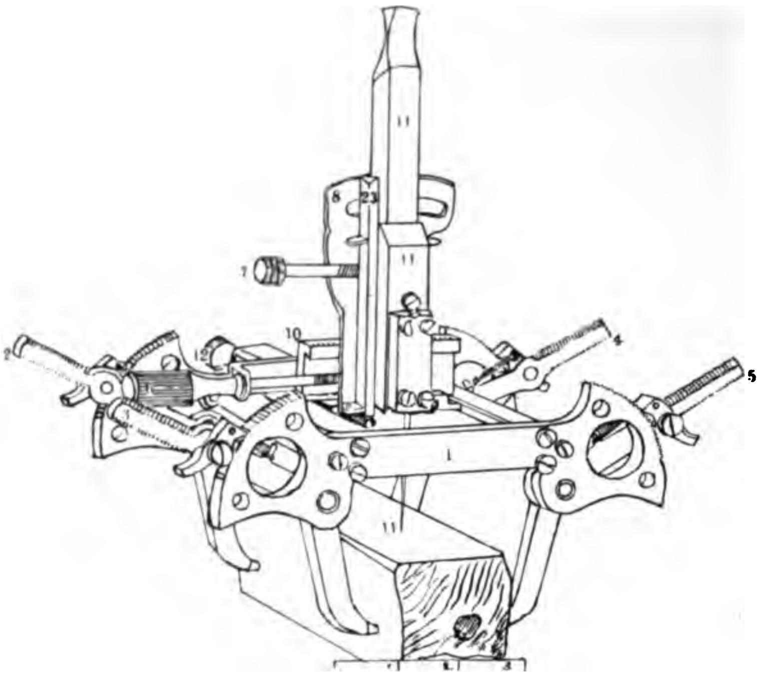


PLATE XXXVIII

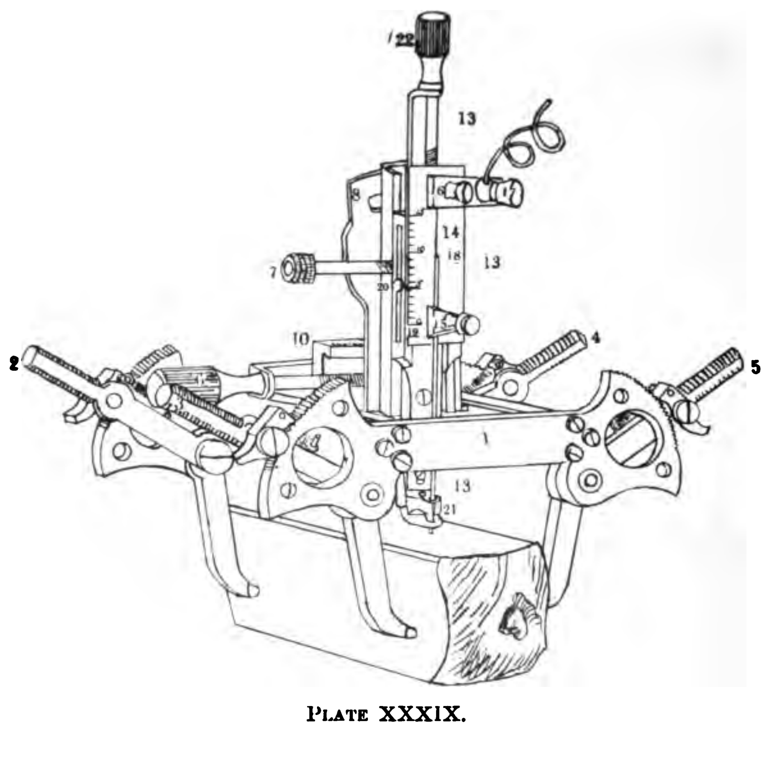


PLATE XXXIX.

Part II

Atlas of Photographs of Sections of the Frozen Cranium of the Monkey and Cat

Frontal Sections of the Rhesus Monkey (*Macacus*)

INTRODUCTION

The accompanying photographs of frontal sections of the cranium of the rhesus monkey form the third part of an atlas of which the first two numbers, representing sagittal and frontal sections of the cat, were published in Germany before the war as supplements of the Journal für Psychologie und Neurologie. The third part was nearly ready when hostilities commenced and would shortly have appeared in the same journal, but of course all arrangements were interrupted and the publication indefinitely postponed, and the course of events makes any prospect of reversion to this arrangement exceedingly remote. Under these circumstances we were glad to avail ourselves of an offer from the Directors of The Johns Hopkins Hospital, Baltimore, to publish this number in the United States. The use of the chart photographs and the method of which they form an essential part were explained in the first number of the atlas. This may not be procurable now, but the subject is discussed in detail in a description of the stereotaxic method and instruments published in the same cover with this fasciculus, rendering a repetition of the explanation unnecessary. It is sufficient to state here that the sections represented are called lamellæ and are approximately one millimeter thick; the head is frozen and the slices cut with a saw parallel to one of the three zero planes by which the cranium is divided for topographical purposes; the other two zero planes, perpendicular to the first, are shown in each photograph as crossed lines, and these together with the number of the lamella furnish the data in every chart for identifying any cubic millimeter in the brain. The photographs are enlarged two diameters and corrections for variations of size in three dimensions are effected by the use of a proportional scale with the saw and the addition of corrected scales for the two dimensions of the chart photographs, when required. A standard cranium near the average size is adopted for each species of animal employed; in the standard all the divisions are millimeters, in heads above or below the standard in any dimension the same number of divisions is maintained, but they measure more or less than

millimeters in the same proportion as the whole dimension varies from the standard.

When the dimensions of heads, selected, either for chart photographs or experimental operations, are very near the standard size, proportional scales are not required and ordinary millimeter scales are employed. The three heads selected for the sections photographed were all sufficiently near the standard size, in the vertical and transverse diameters, to make proportional scales for these dimensions unnecessary and ordinary millimeter scales may be used.

We prepared a complete series of two plates for each lamella from Posterior Frontal Lamella XXVI to Anterior Frontal Lamella XL. One named and the other untouched. Owing to the greatly increased cost of production it was not possible to reproduce them all, but the selection made will be found sufficient for practical purposes.

We have introduced a few other anatomical photographs which those who employ the instrument for experimental work may find useful.

The first three illustrations (Plate XL) represent the surface of the brain of the rhesus with the names of the convolutions and fissures usually adopted and followed in naming the sections; they may be of service for reference and comparison with the photographs of the sections.

The next three photographs (Plate XLI) show the relations of the frontal and horizontal zero planes to: (1) The lateral aspect of the cranium; (2) the same with the bone removed to expose the surface of the brain; and (3) the median sagittal section of the cranium and brain in the rhesus monkey. Plate XLII shows the relations of the same zero planes to median sagittal sections of the cerebellum of the cat and rhesus monkey and the corresponding divisions of the vermis in those animals, and Plate XLIII consists of a series of photographs, from different aspects, of the cerebellum of the rabbit, cat and rhesus monkey, for the comparison of corresponding structures in the three animals most often employed by the experimental neurologist. We should have liked to carry this comparative study a good deal further, for we think it important and likely to throw light on the functions of the cerebellum. We must take this opportunity of once more expressing our grateful acknowledgment to Professor Vaughan Harley and Dr. Goodbody (Assistant Professor) at University College, who have

afforded us all the assistance in their power and the accommodation available in a period of continuous migration from room to room occasioned by the demolition of old laboratories and the erection of new ones, until finally the new buildings were taken over by the War Office. We also wish to express our thanks to the Royal Society for a grant of £30 towards the expenses of this work.

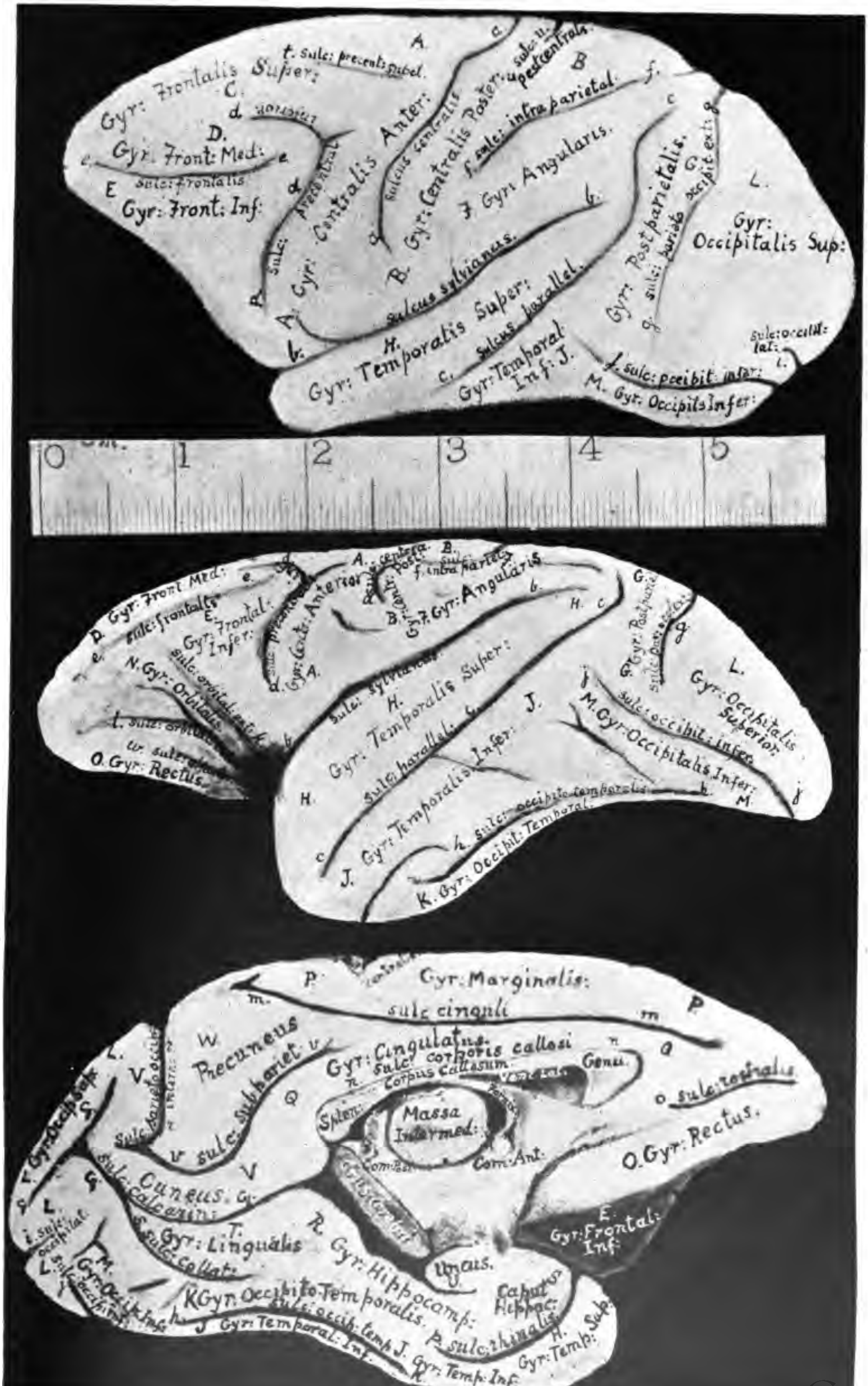


PLATE XL.—Brain of rhesus monkey. 1, lateral view, upper half; 2, lateral view, lower half; 3, lateral view, median sagittal section. (Enlarged 2 diameters.)

Median surface of right hemisphere.

Left hemisphere of brain, outer surface.

Surface of skull from left side.

XLI.—Projection of zero planes on cranium and brain of rhesus *in situ*. (Natural size. Dimensions of standard rhesus in millimeters.)

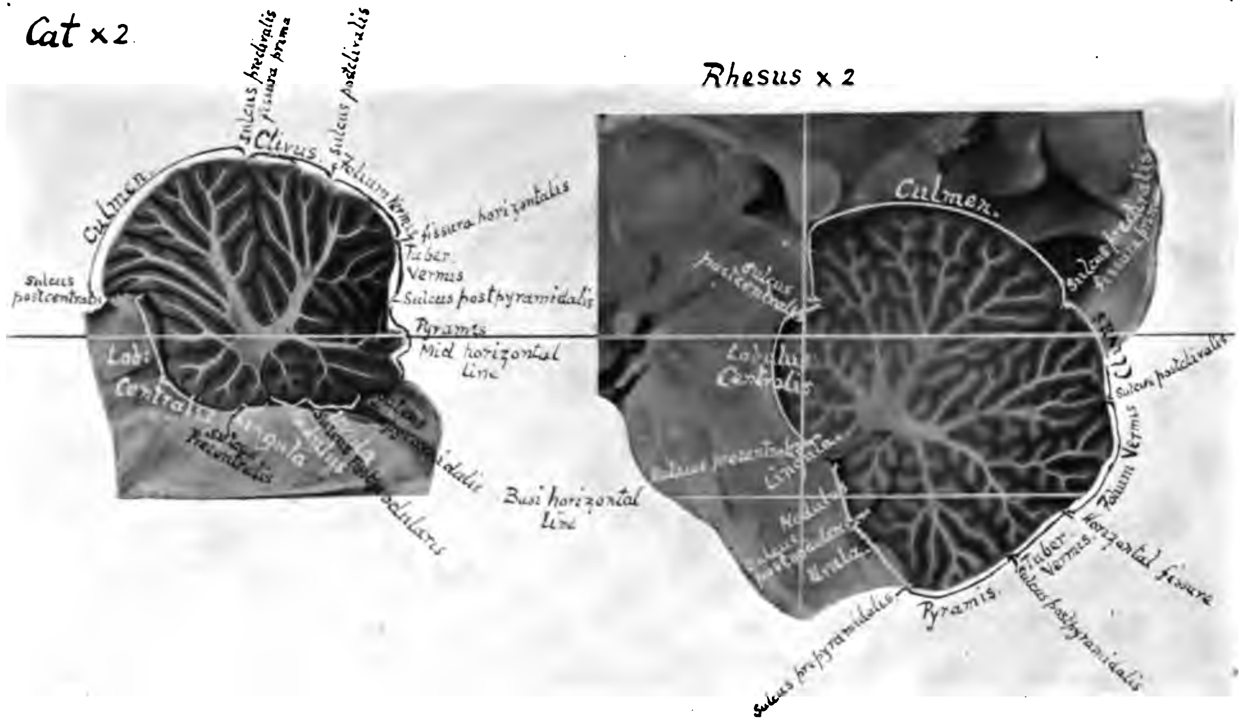


Plate XLII.—Median sagittal section of vermis of cerebellum in rhesus monkey and cat, showing corresponding divisions and relations to horizontal zero planes in corresponding positions. (Enlarged 2 diameters.)

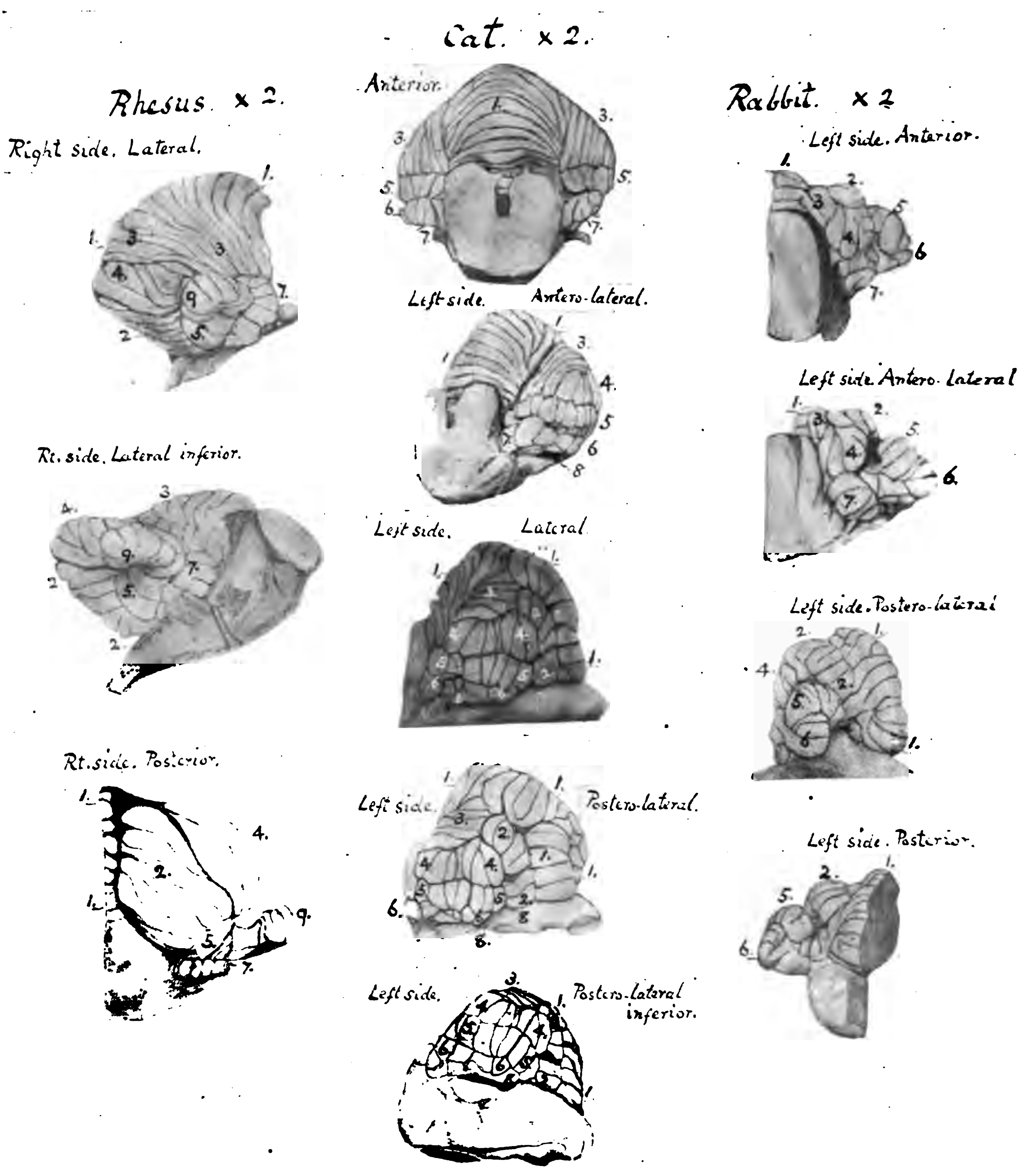
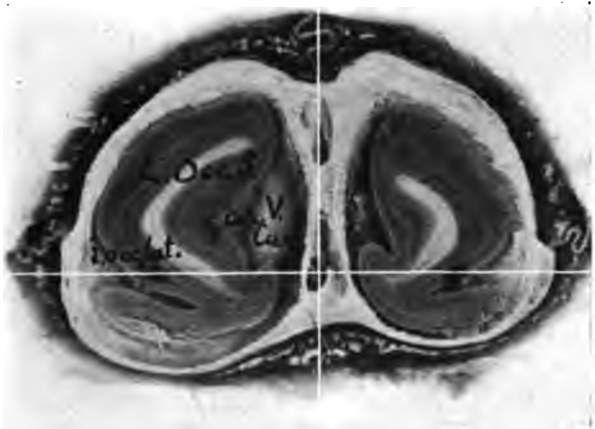
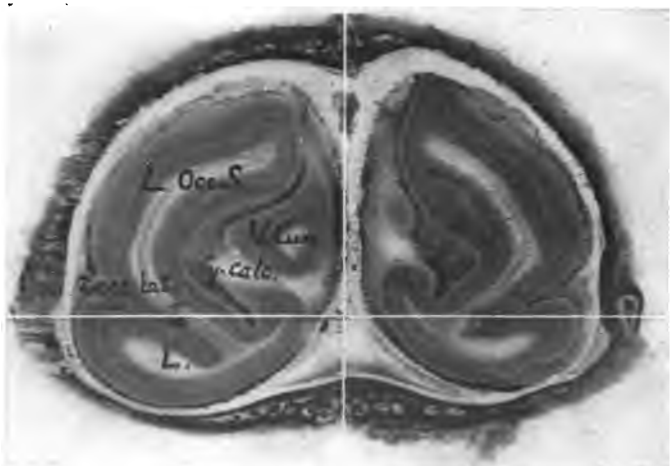


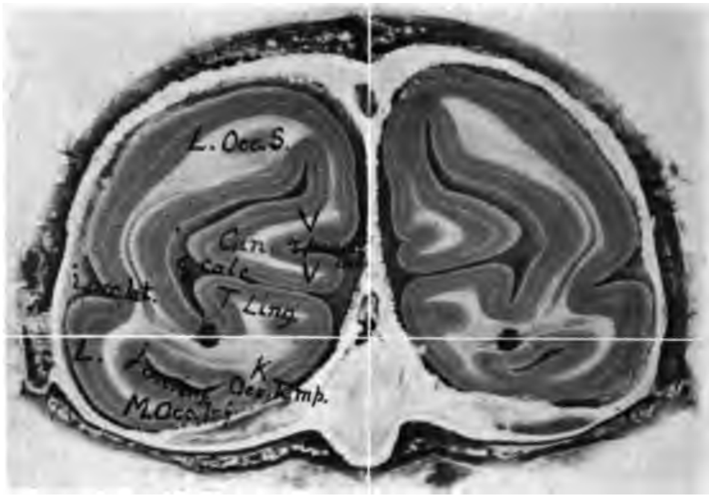
PLATE XLIII.—Illustrations of cerebellum of rhesus monkey, cat and rabbit, showing corresponding structures. (Enlarged 2 diameters.) 1, vermis; 2, paramesial lobule; 3, anterior pennate lobule; 4, posterior pennate lobule; 5, dorsal paraflocculus; 6, ventral paraflocculus; 7, flocculus; 8, peduncle of flocculus; 9, dorsal paraflocculus, lateral process. (Reduced 1/6.)



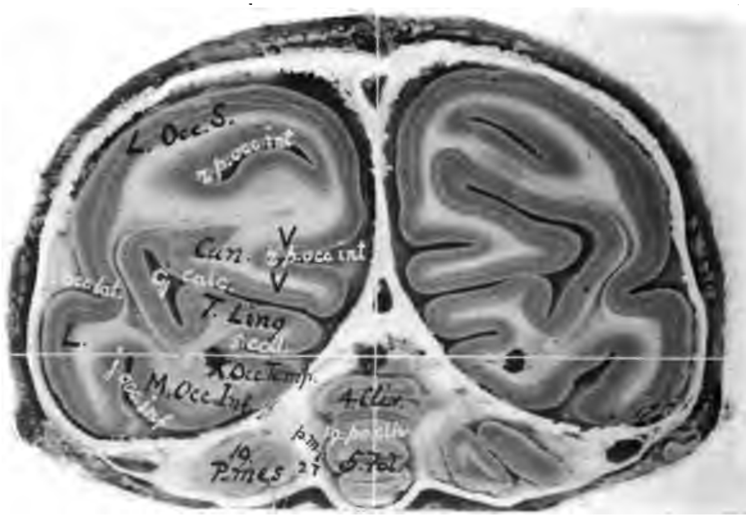
POSTERIOR FRONTAL LAMELLA. XXV.



POSTERIOR FRONTAL LAMELLA. XXIII.

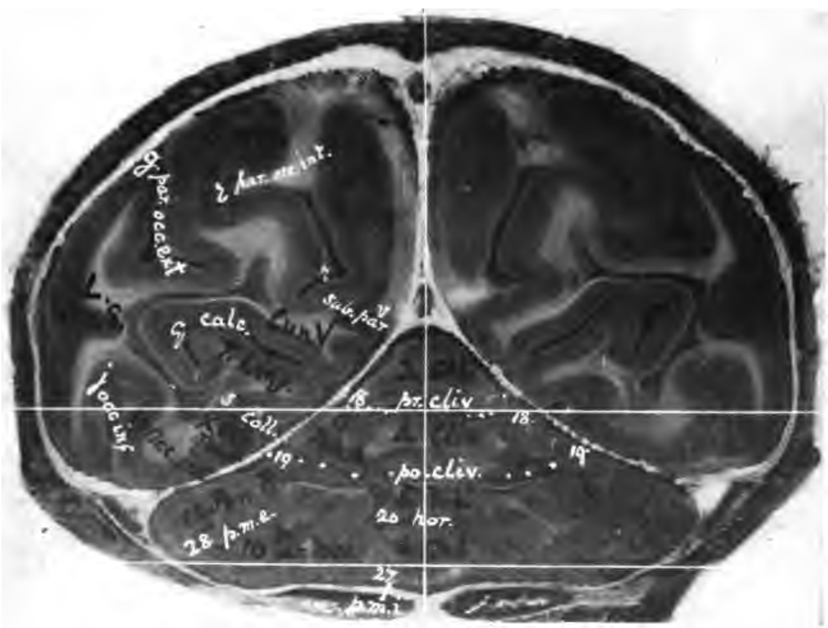


Posterior Frontal Lamella. XXI.



Posterior Frontal Lamella. XIX.

Posterior Frontal Lamella. XVII.

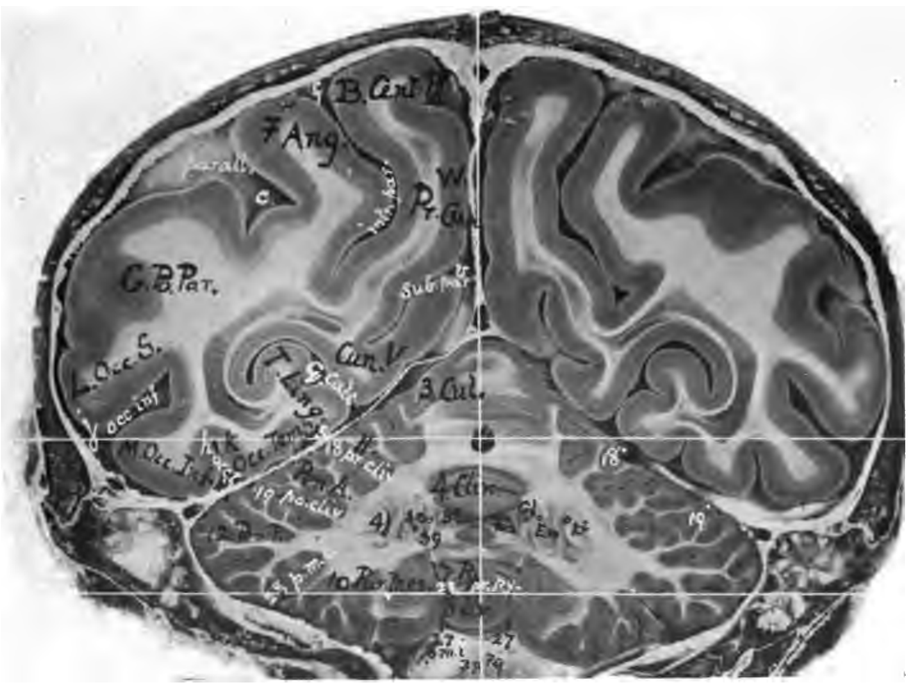


Posterior Frontal Lamella. XV.

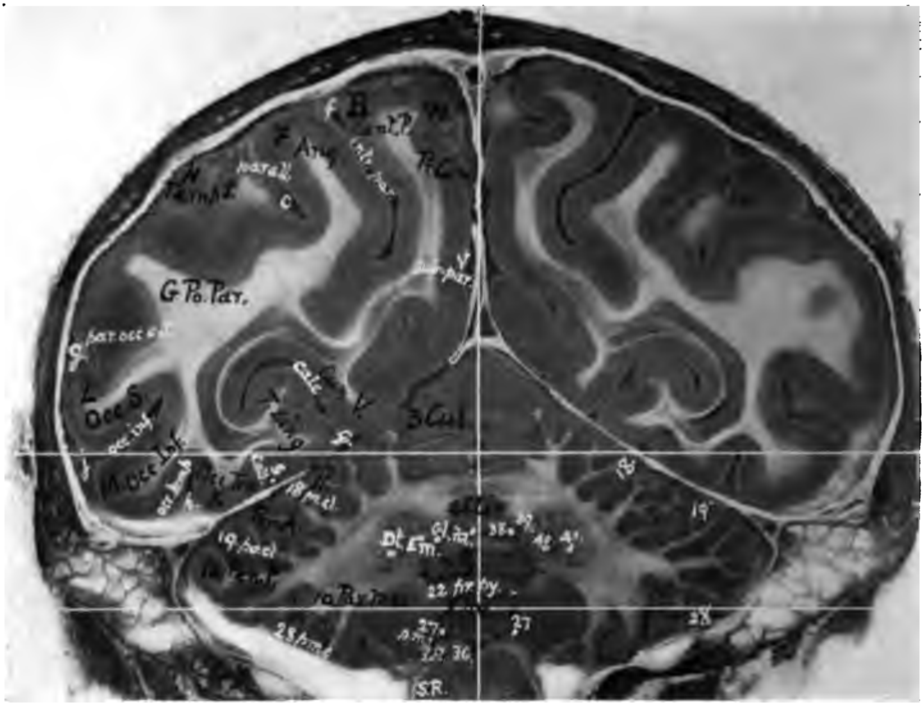
POSTERIOR FRONTAL LAMELLA. XIII.

POSTERIOR FRONTAL LAMELLA. XI.

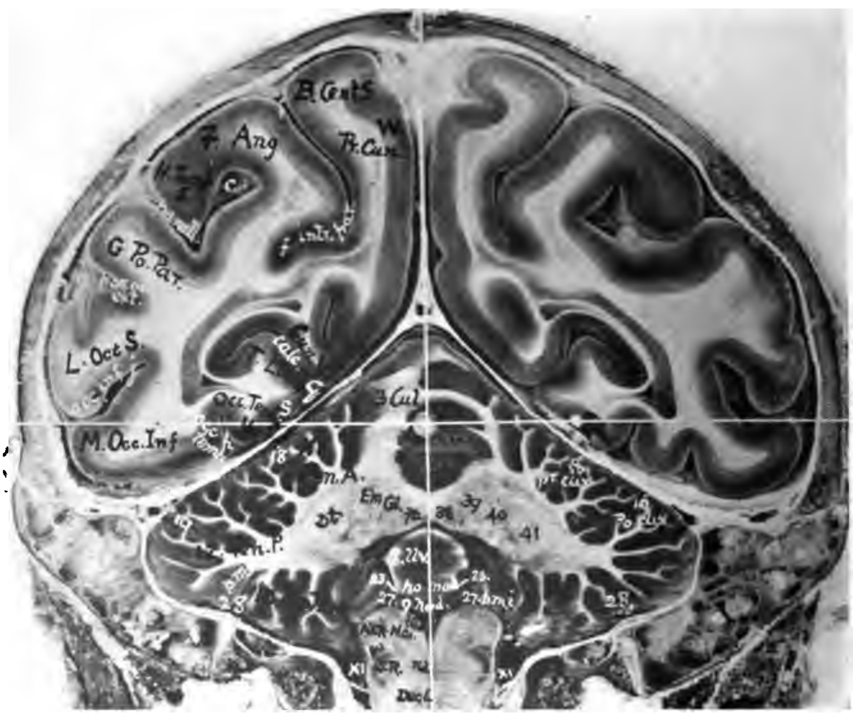
Posterior Frontal Lamella. X.



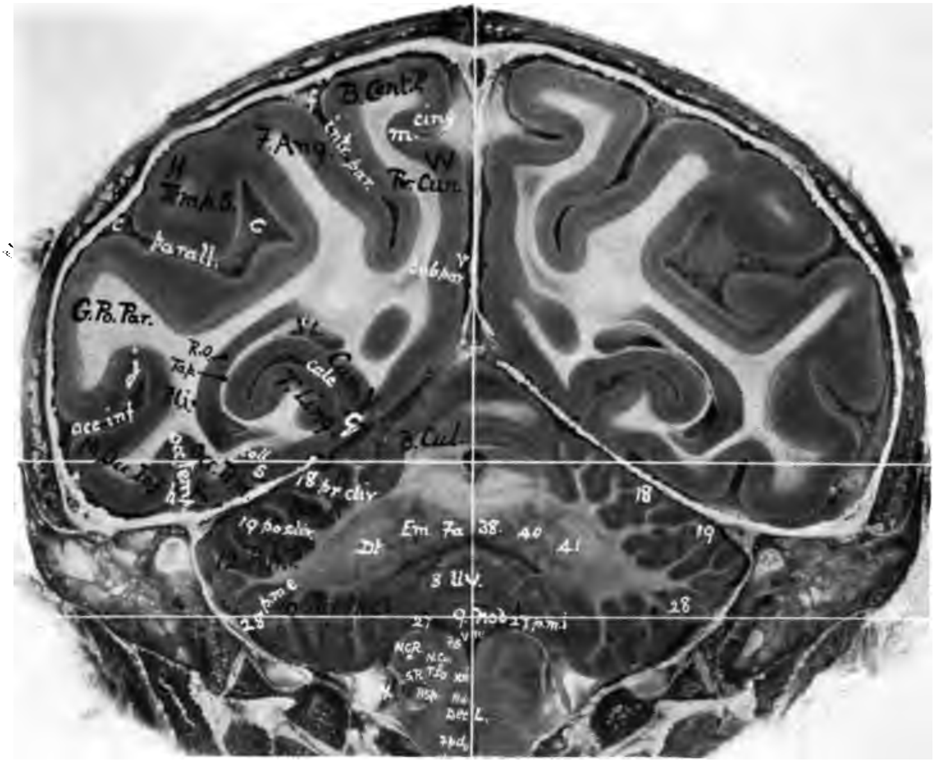
Posterior Frontal Lamella. IX.



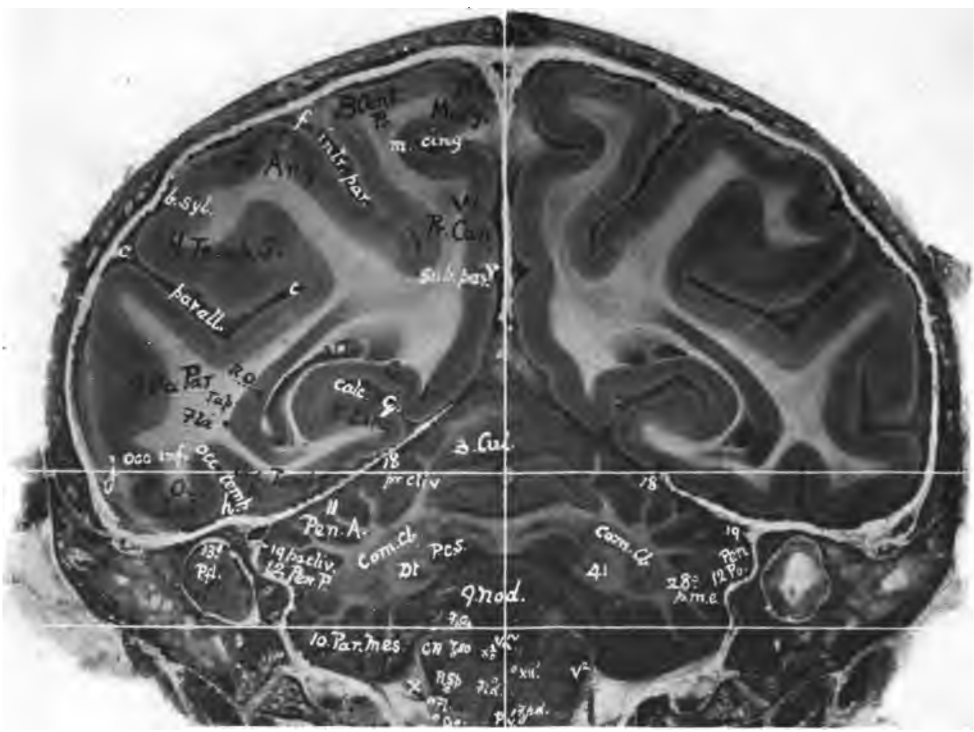
POSTERIOR FRONTAL LAMELLA. VIII.



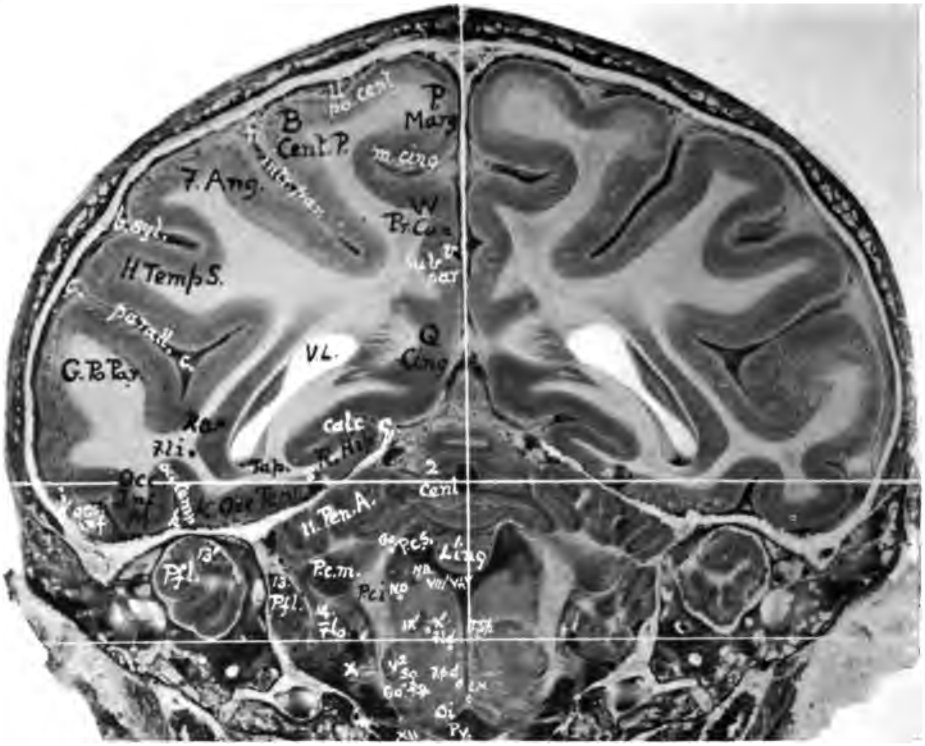
POSTERIOR FRONTAL LAMELLA. VII.



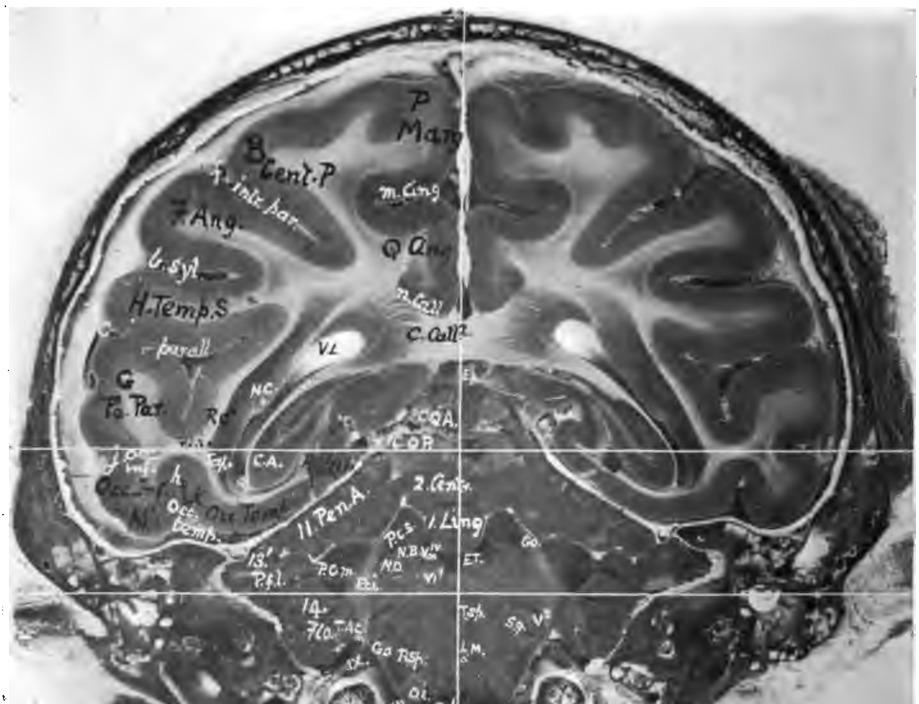
Posterior Frontal Lamella. VI.



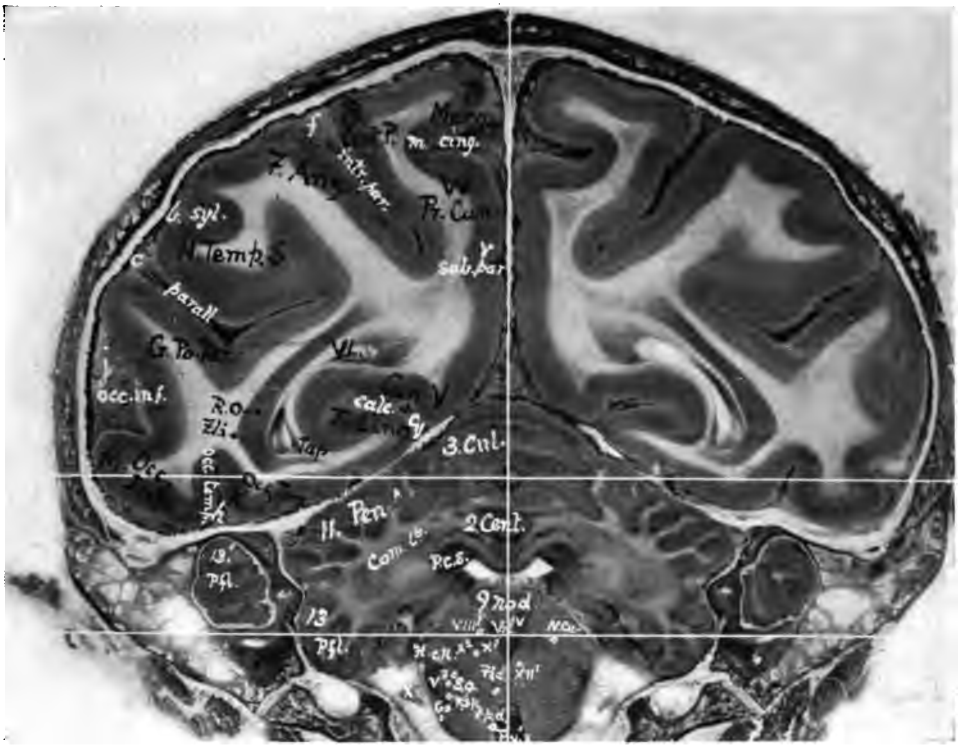
Posterior Frontal Lamella. V.



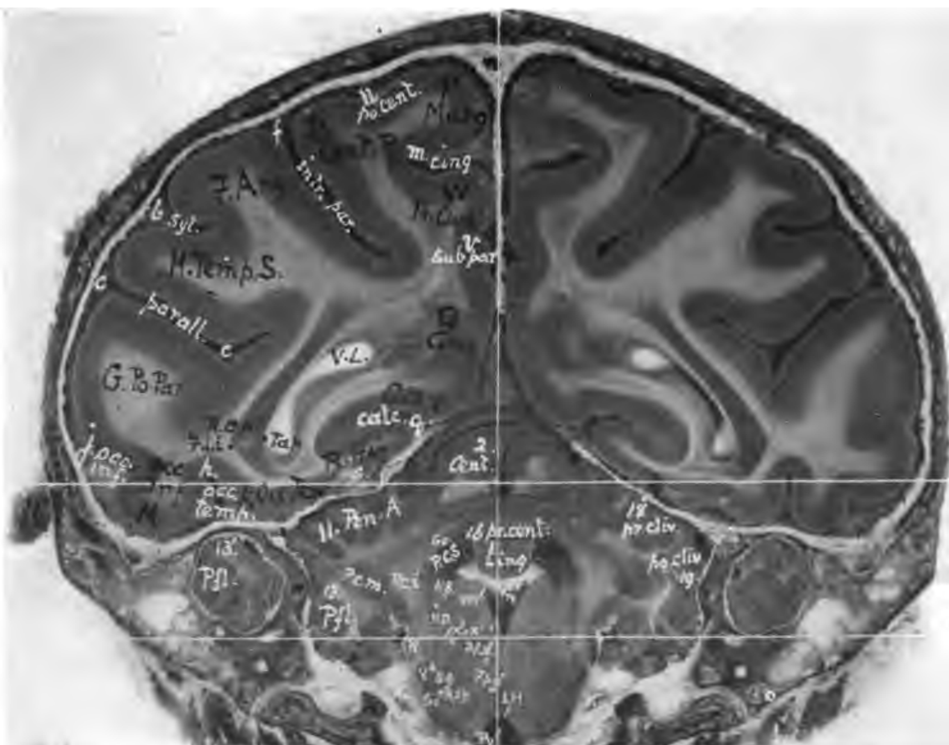
POSTERIOR FRONTAL LAMELLA. IV.



POSTERIOR FRONTAL LAMELLA. III.

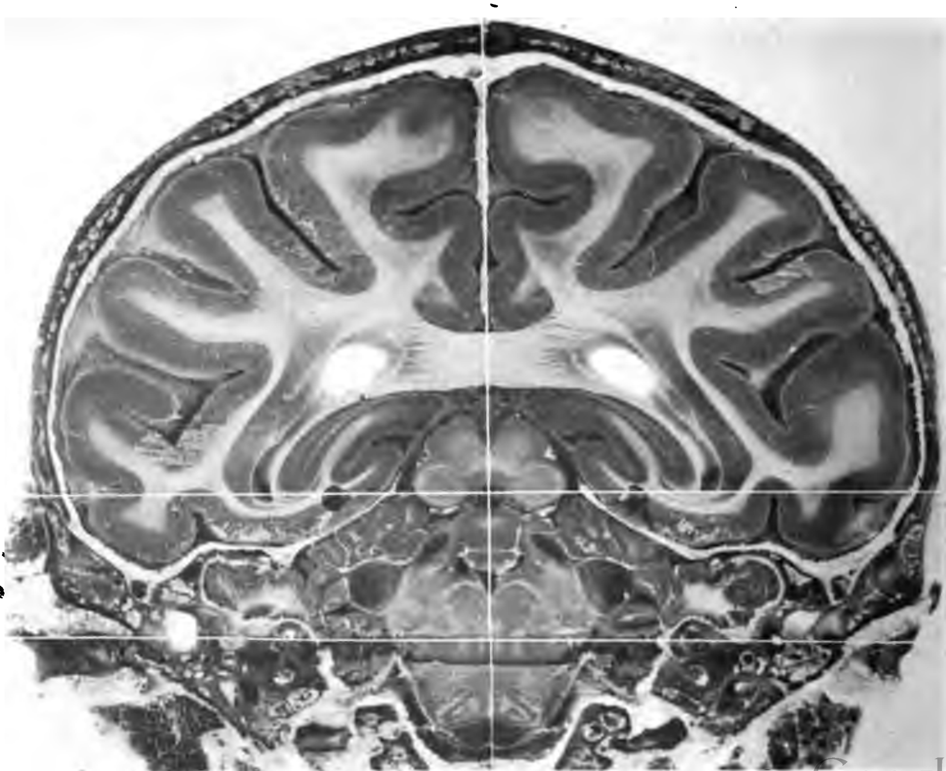


POSTERIOR FRONTAL LAMELLA. II.

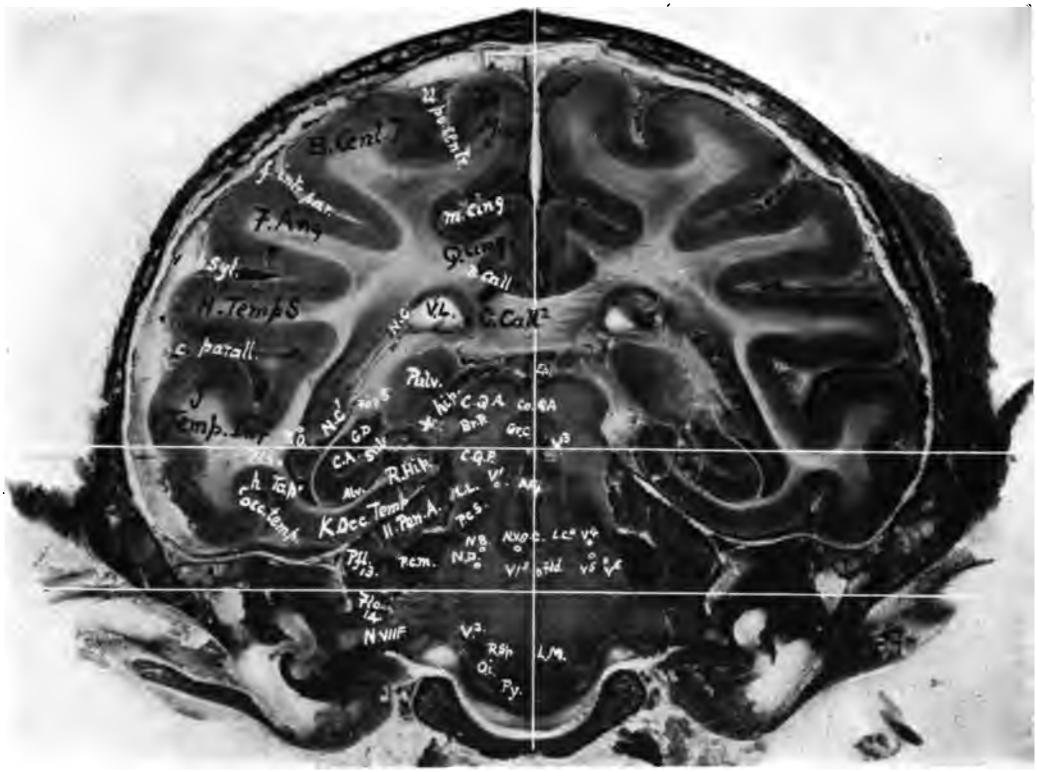


POSTERIOR FRONTAL LAMELLA. I.

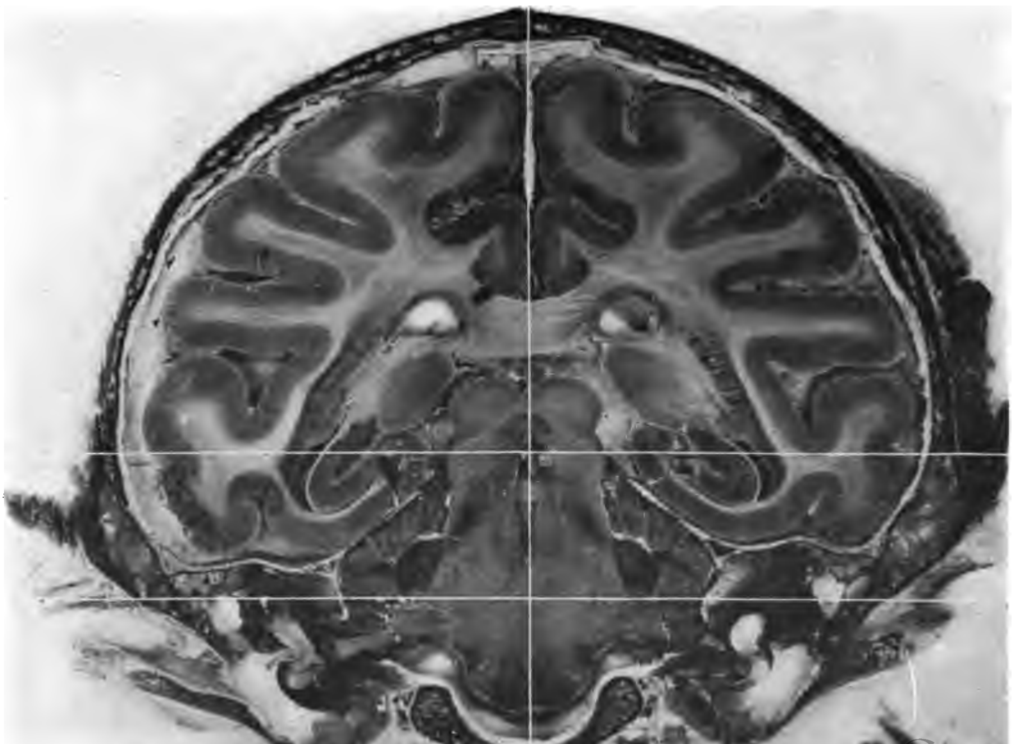
ANTERIOR FRONTAL LAMELLA. I.



ANTERIOR FRONTAL LAMELLA. I.



ANTERIOR FRONTAL LAMELLA. II.

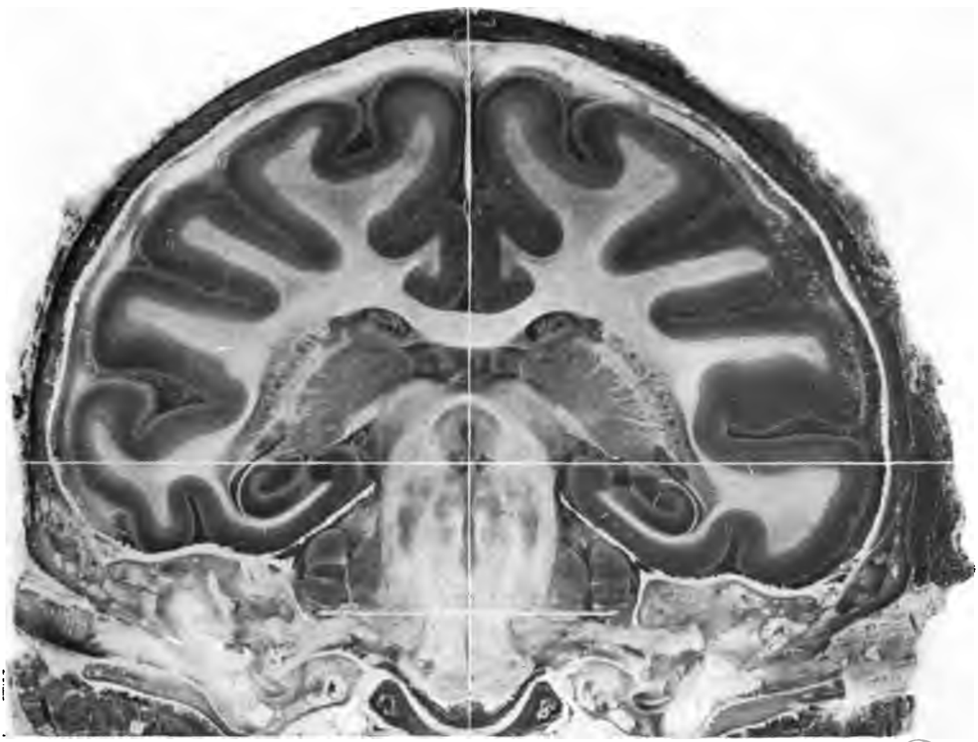


ANTERIOR FRONTAL LAMELLA. II.

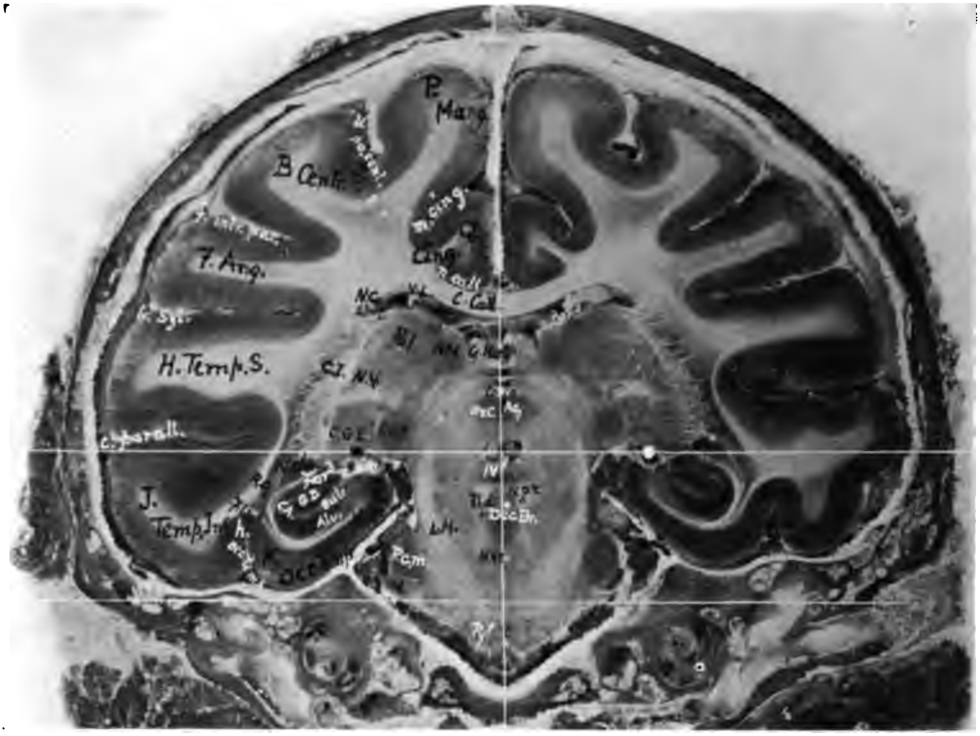
ANTERIOR FRONTAL LAMELLA. III.

ANTERIOR FRONTAL LAMELLA. III.

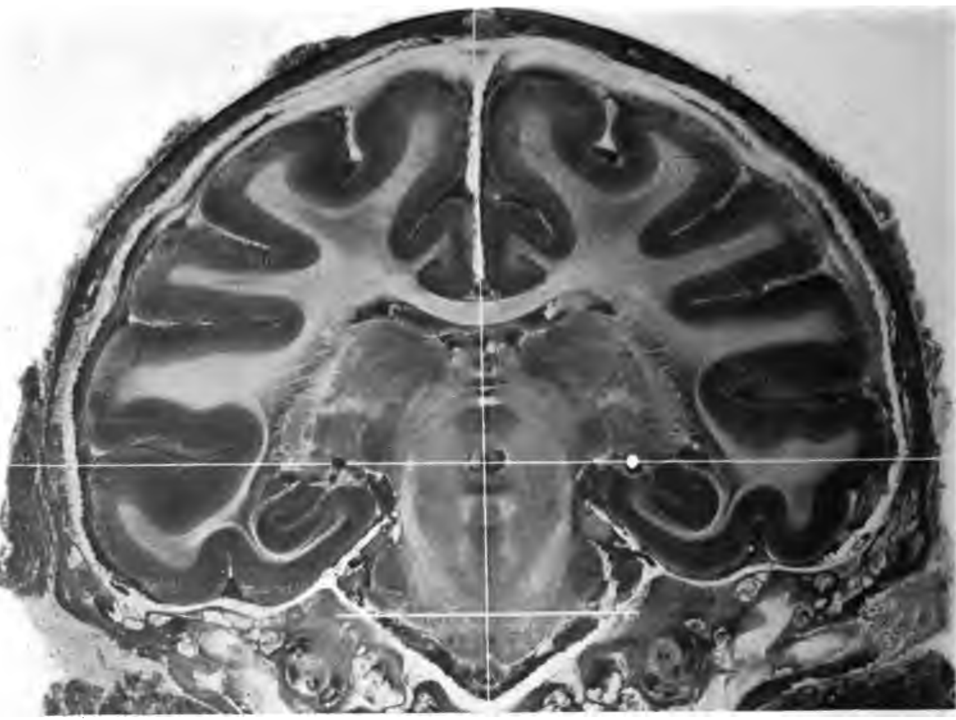
ANTERIOR FRONTAL LAMELLA. IV.



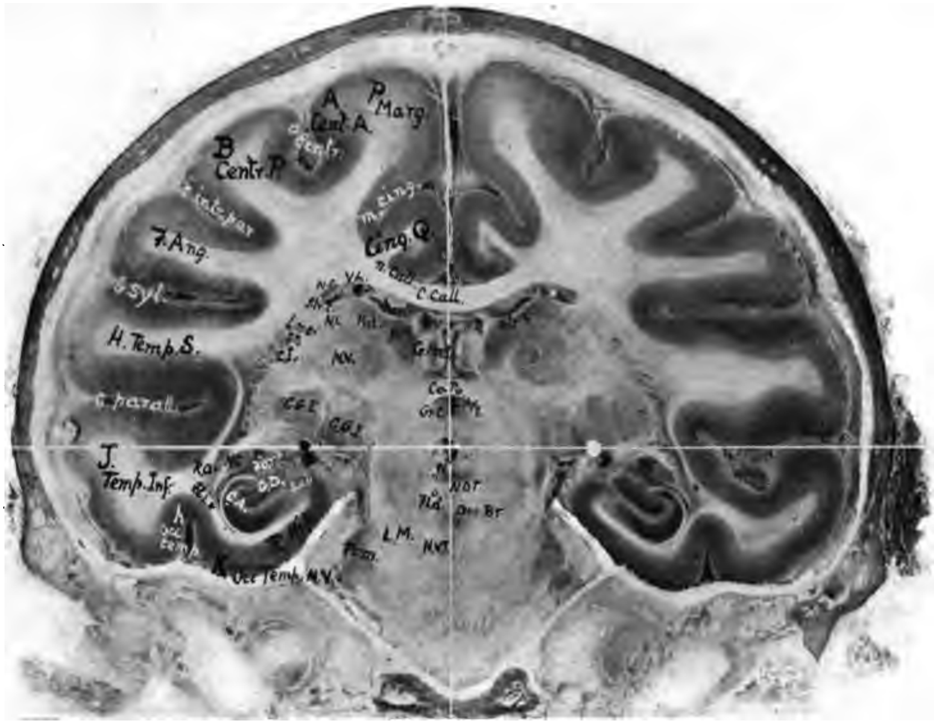
ANTERIOR FRONTAL LAMELLA. IV.



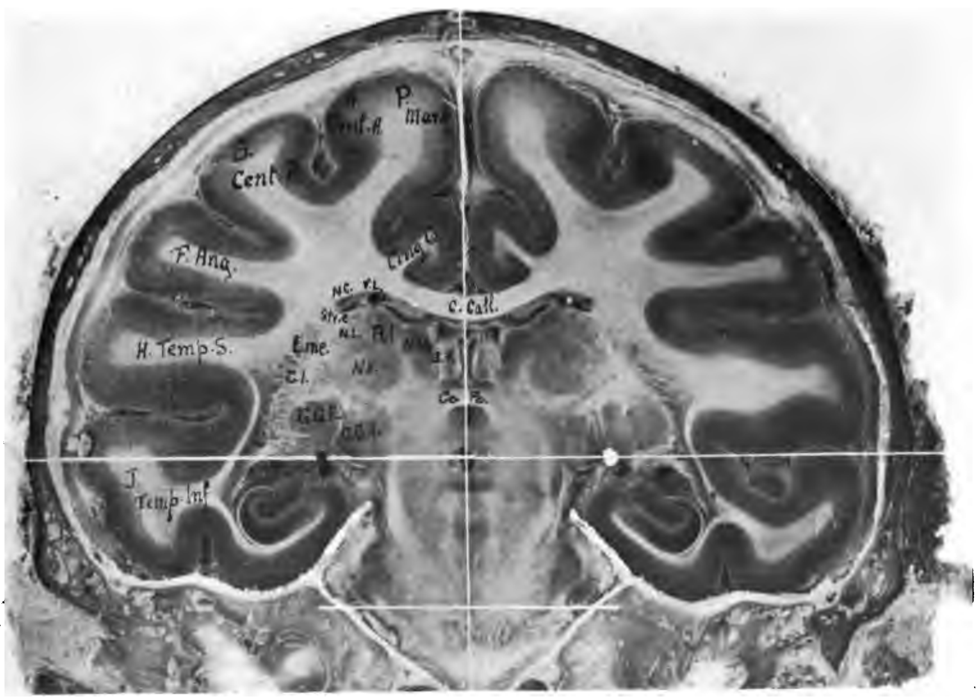
ANTERIOR FRONTAL LAMELLA. V.



ANTERIOR FRONTAL LAMELLA. V.



ANTERIOR FRONTAL LAMELLA. VI.



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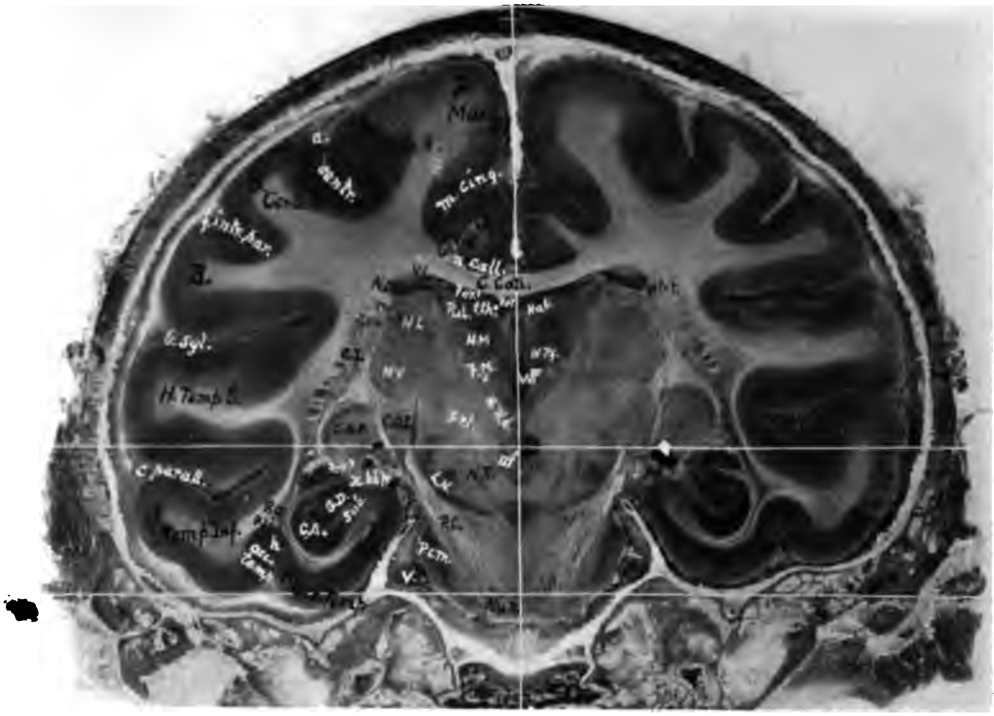
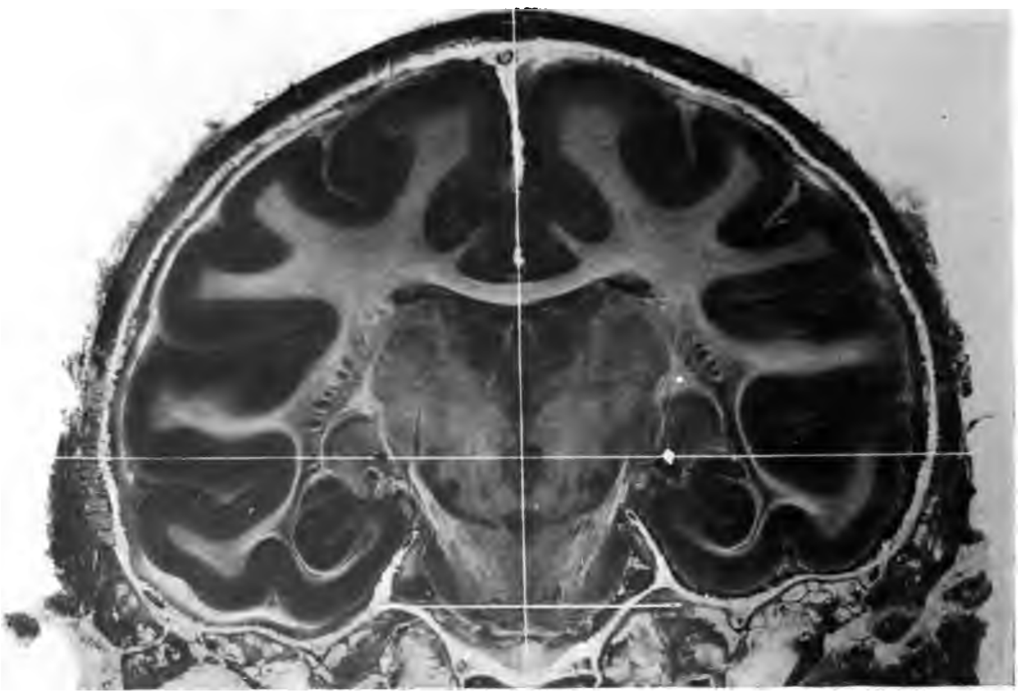


ANTERIOR FRONTAL LAMELLA. VII.



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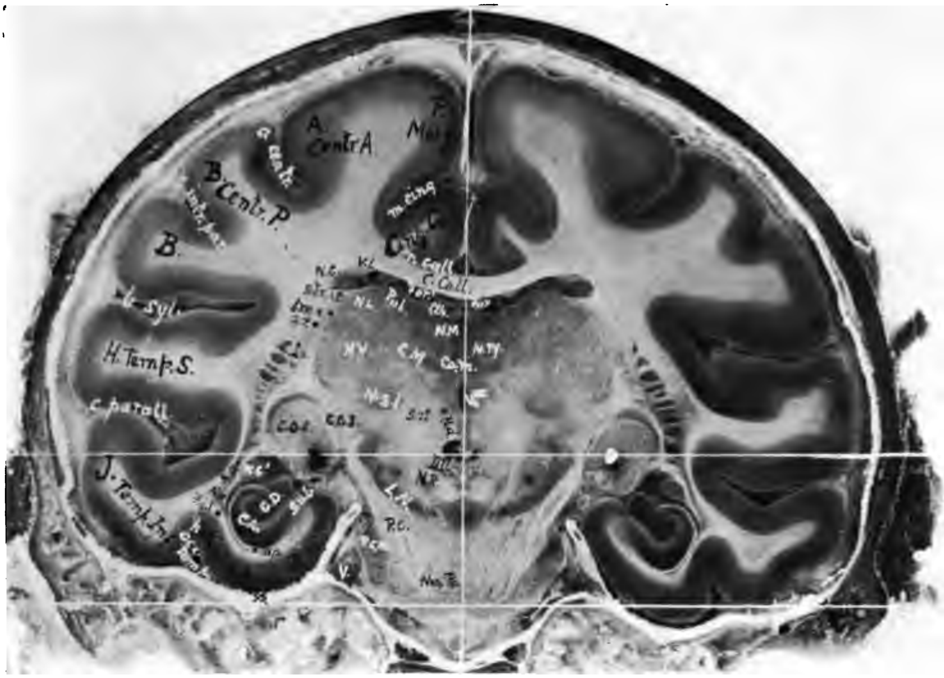
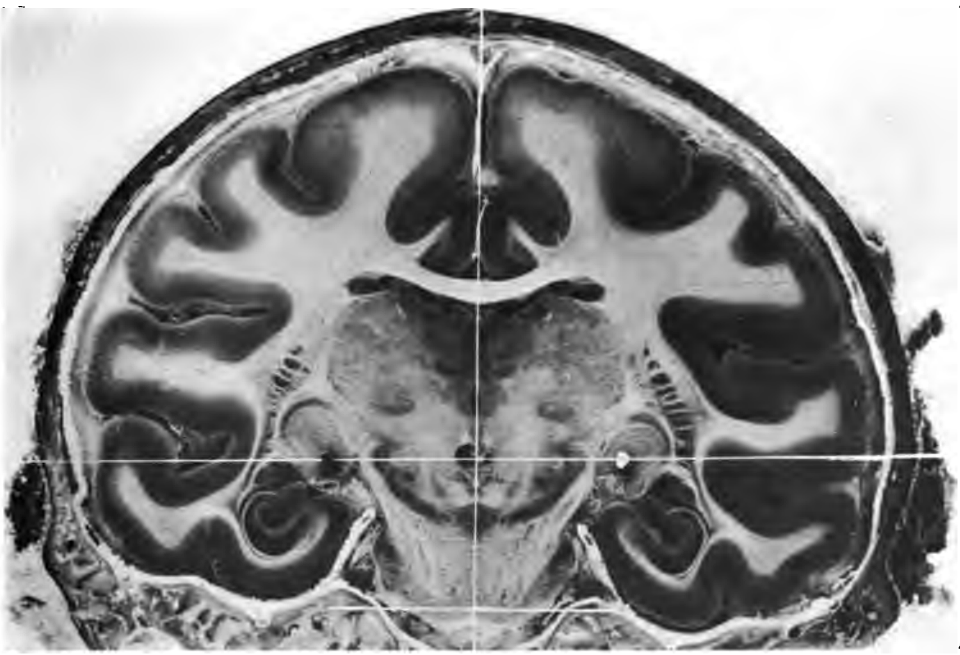
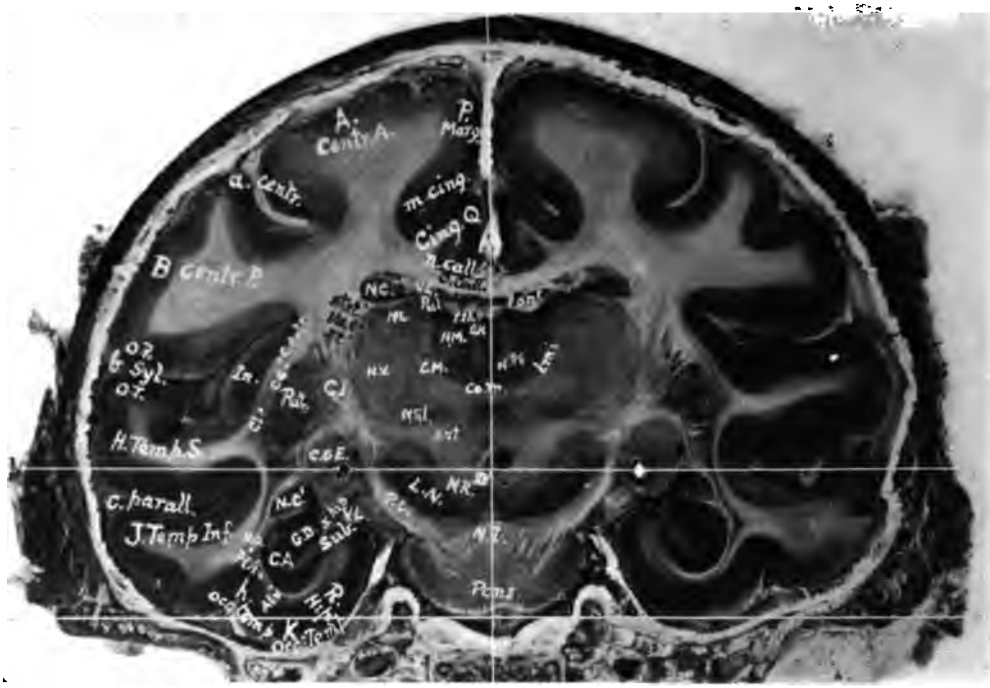


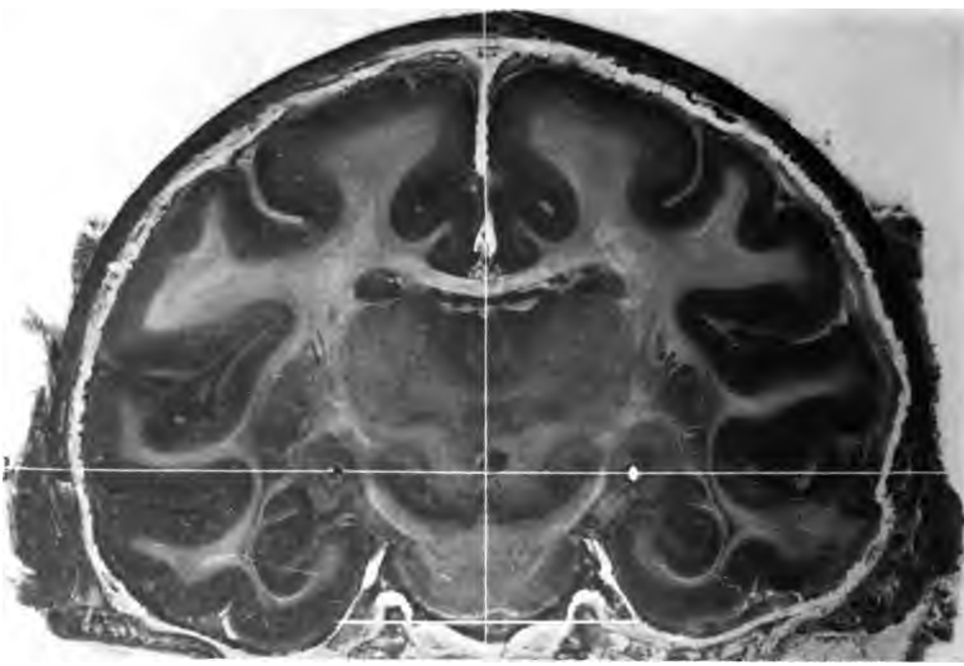
Anterior Frontal Lamella. VIII.



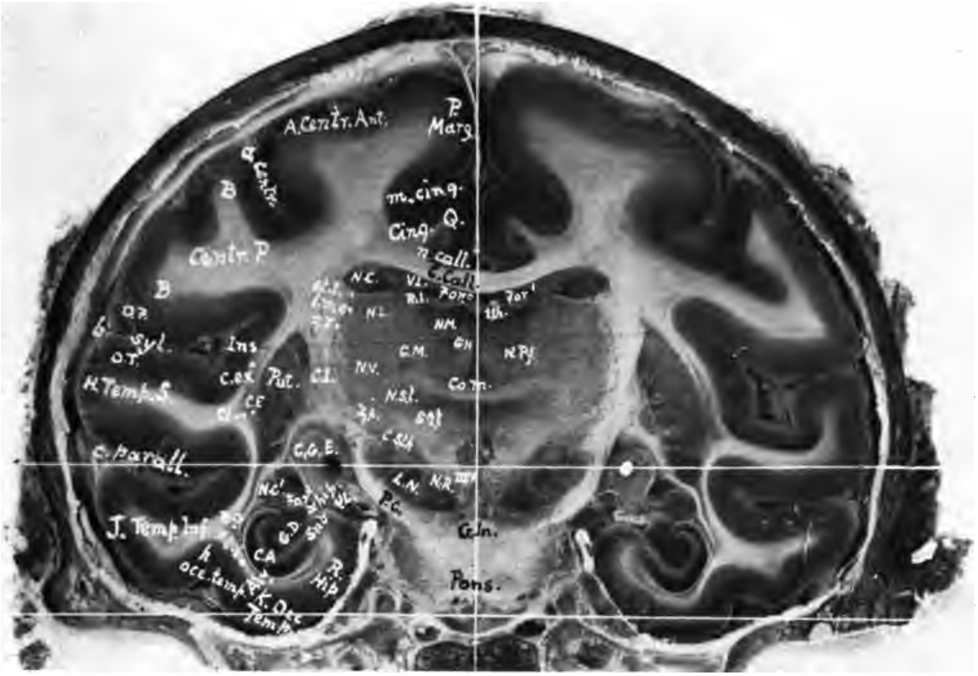
Anterior Frontal Lamella. VIII.



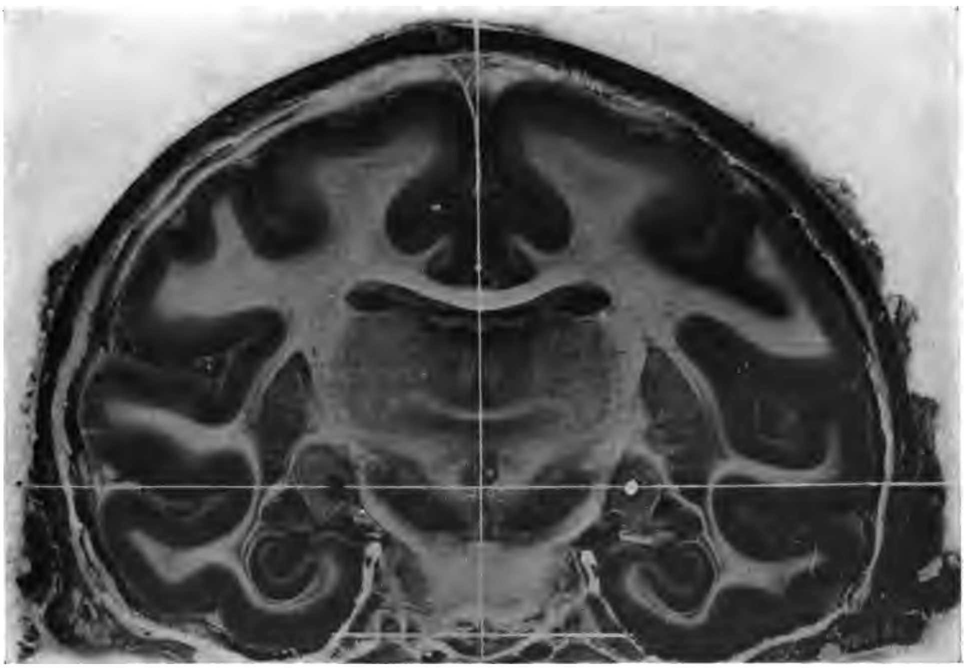
ANTERIOR FRONTAL LAMELLA. IX.



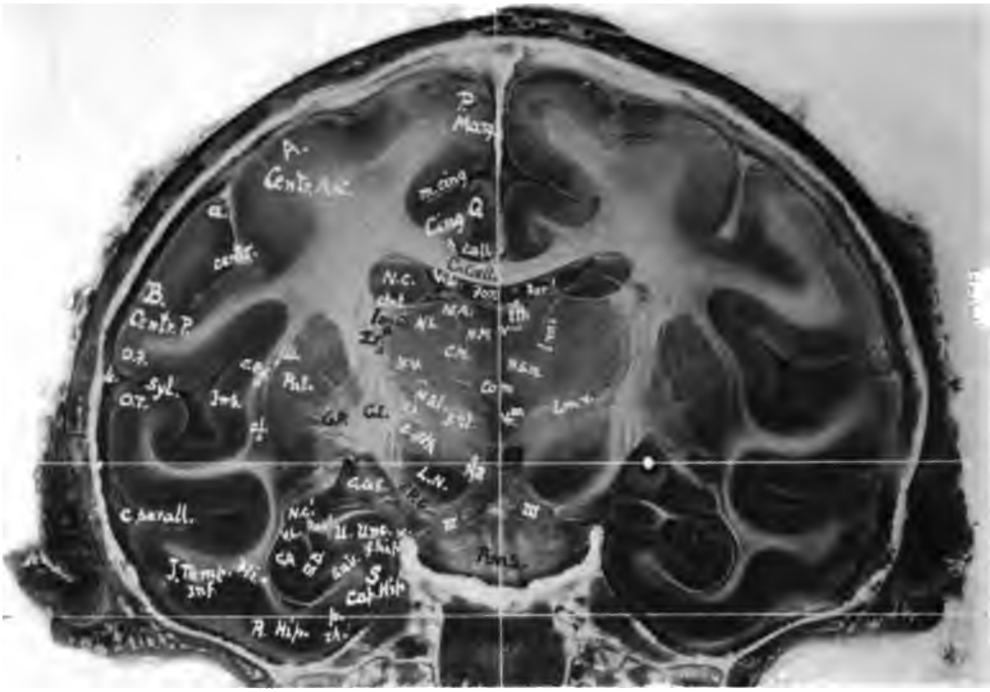
ANTERIOR FRONTAL LAMELLA. IX.



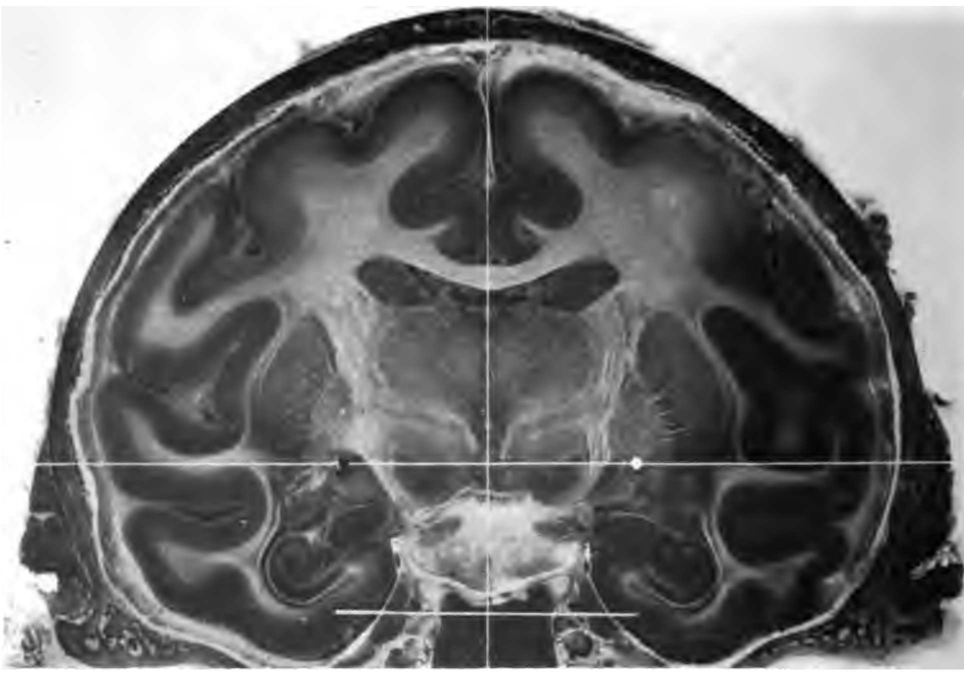
Anterior Frontal Lamella. X.



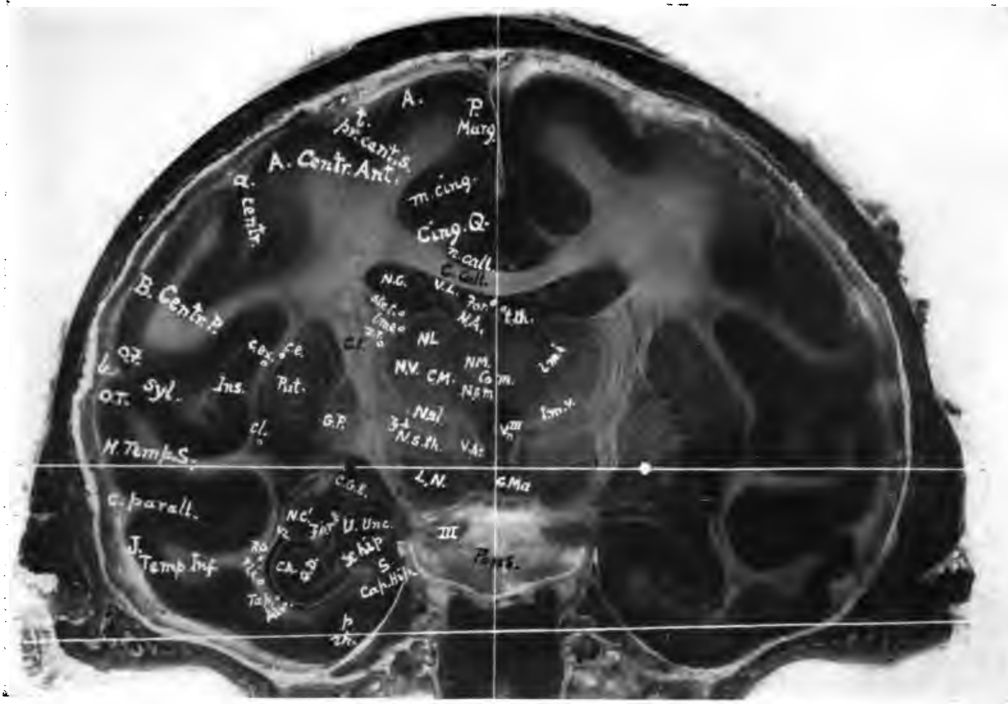
Anterior Frontal Lamella. X.



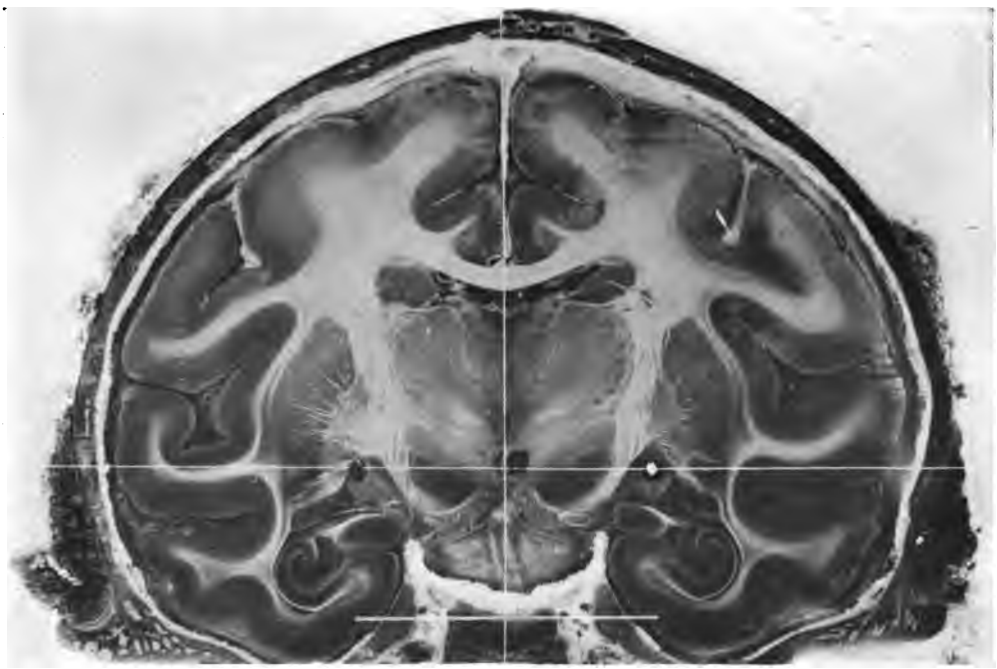
ANTERIOR FRONTAL LAMELLA. XI.



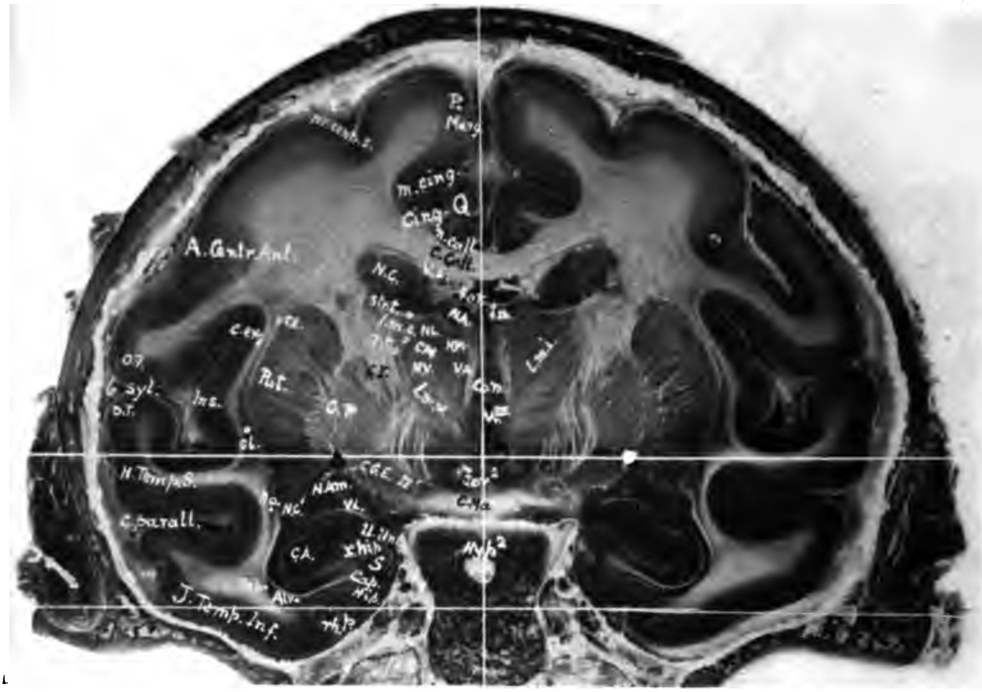
ANTERIOR FRONTAL LAMELLA. XI.



ANTERIOR FRONTAL LAMELLA. XII.

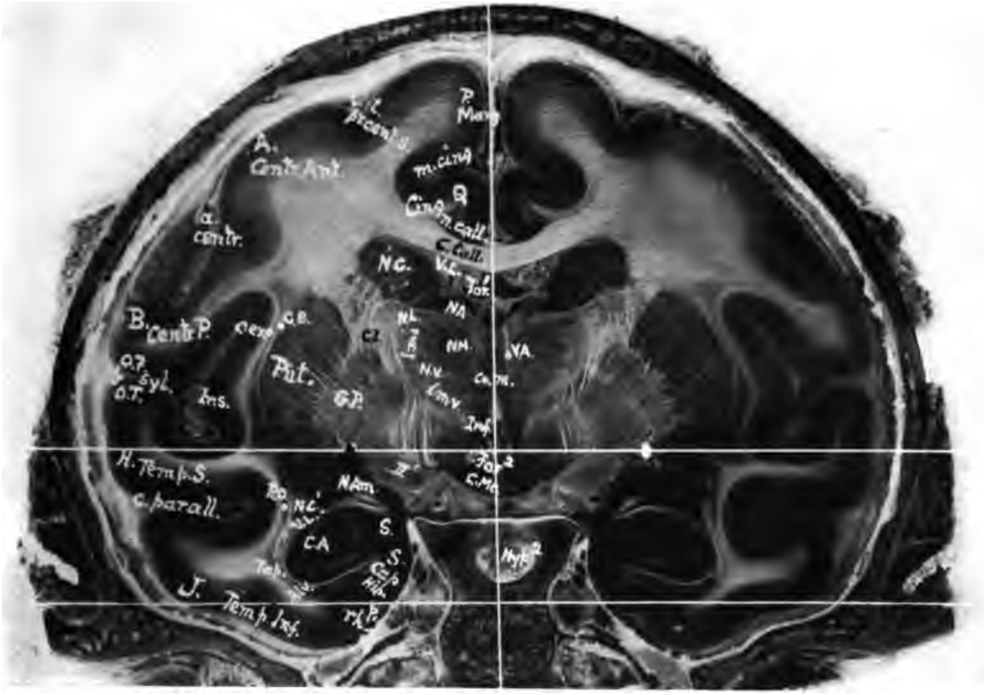


ANTERIOR FRONTAL LAMELLA. XII.

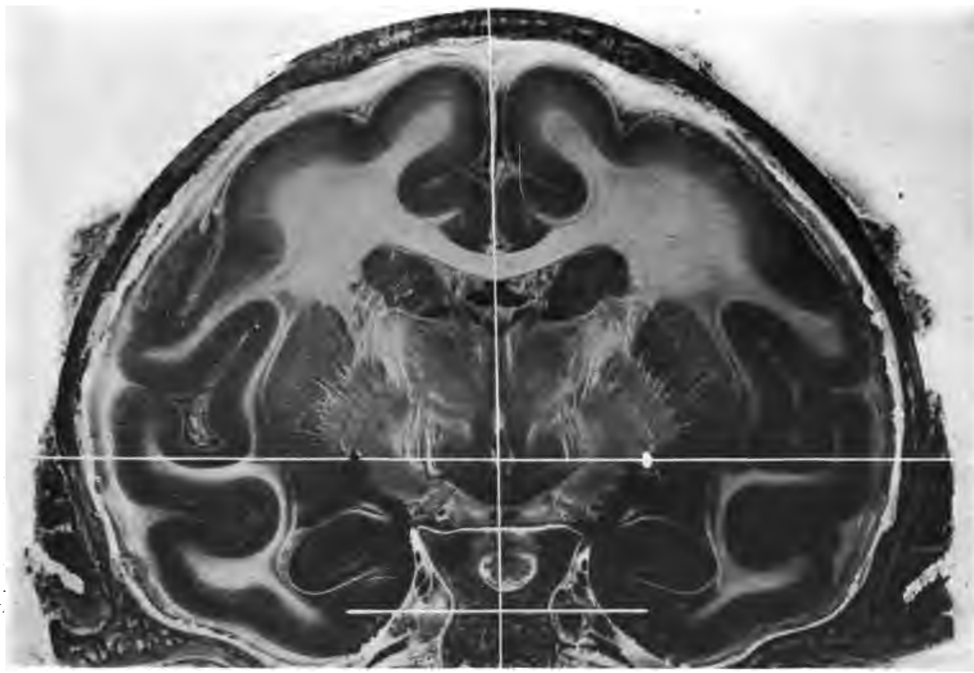


Anterior Frontal Lamella. XIII.

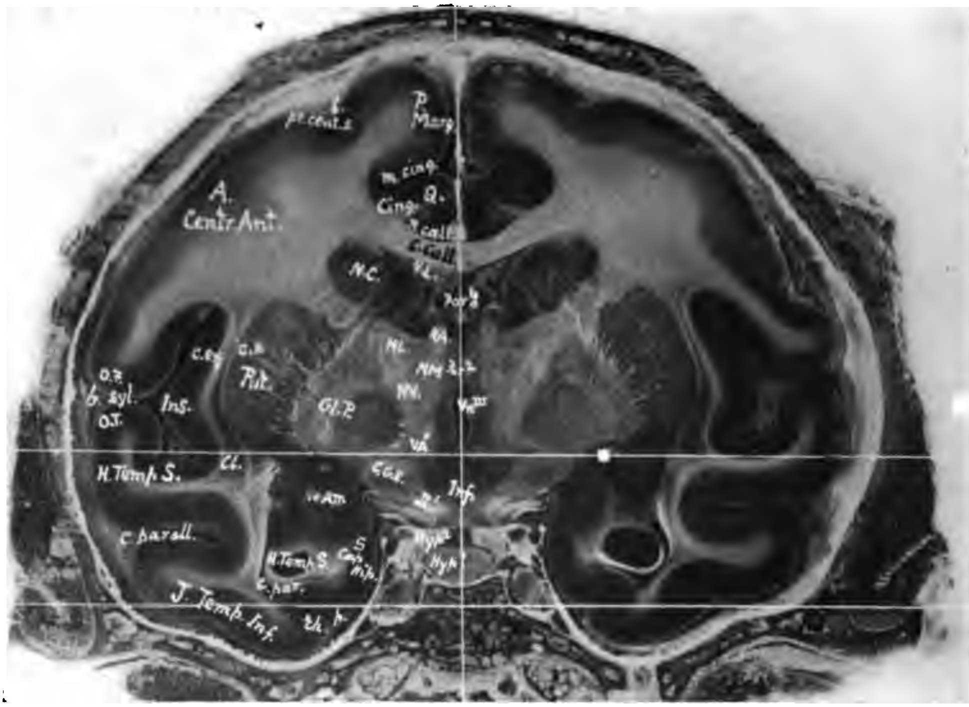
Anterior Frontal Lamella. XIII.



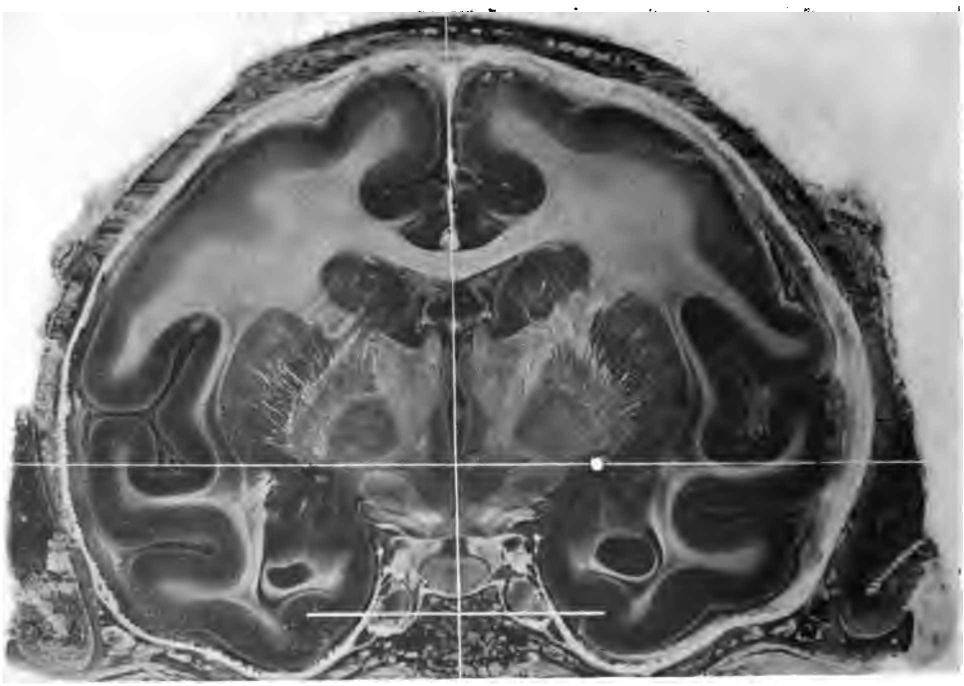
ANTERIOR FRONTAL LAMELLA. XIV.



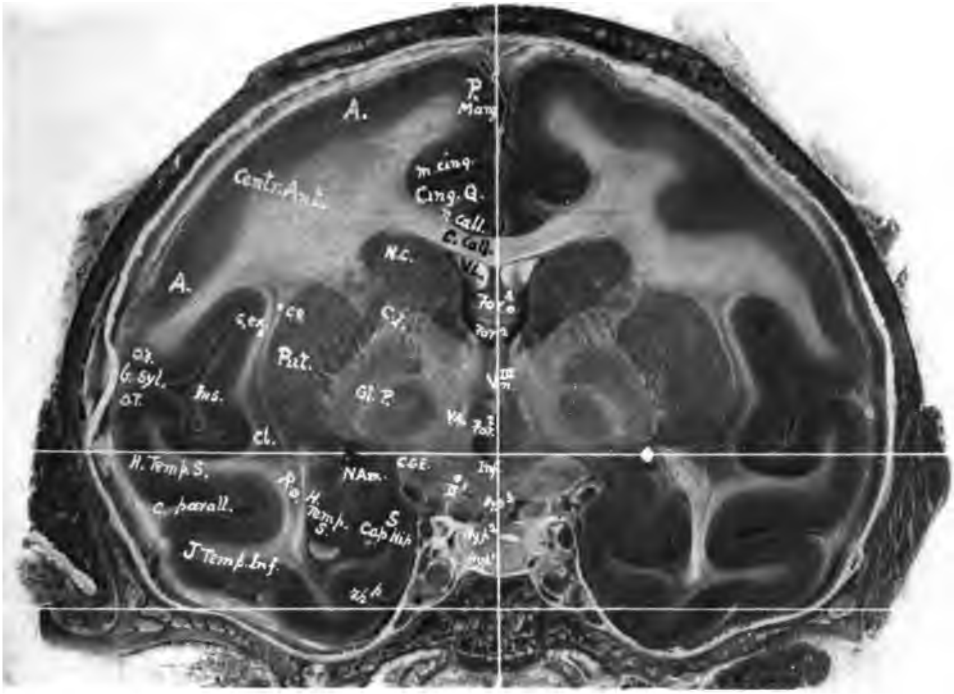
ANTERIOR FRONTAL LAMELLA. XIV.



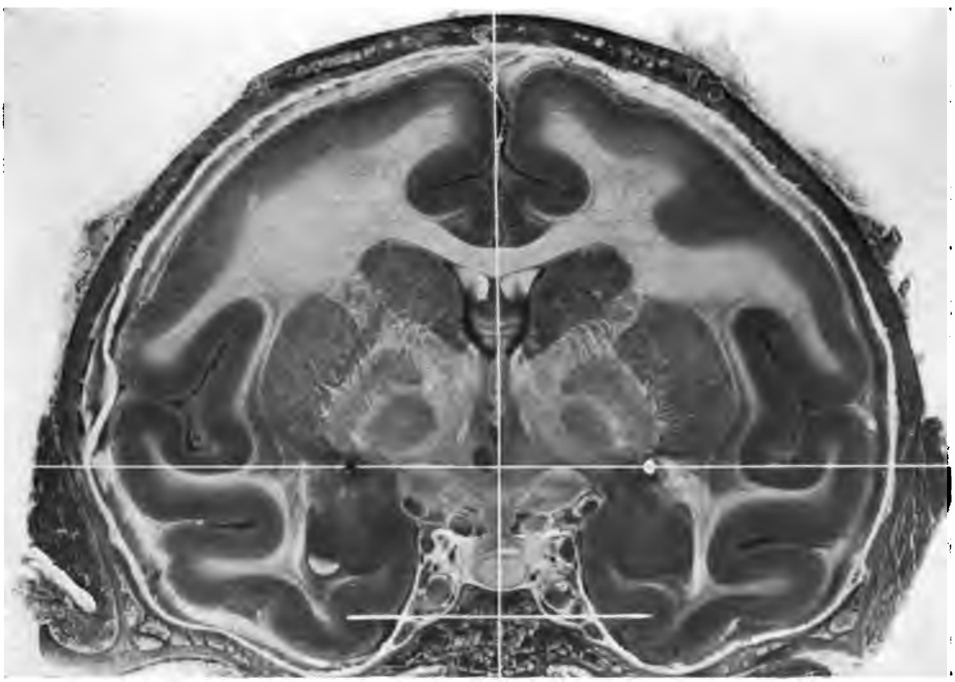
ANTERIOR FRONTAL LAMELLA. XV.



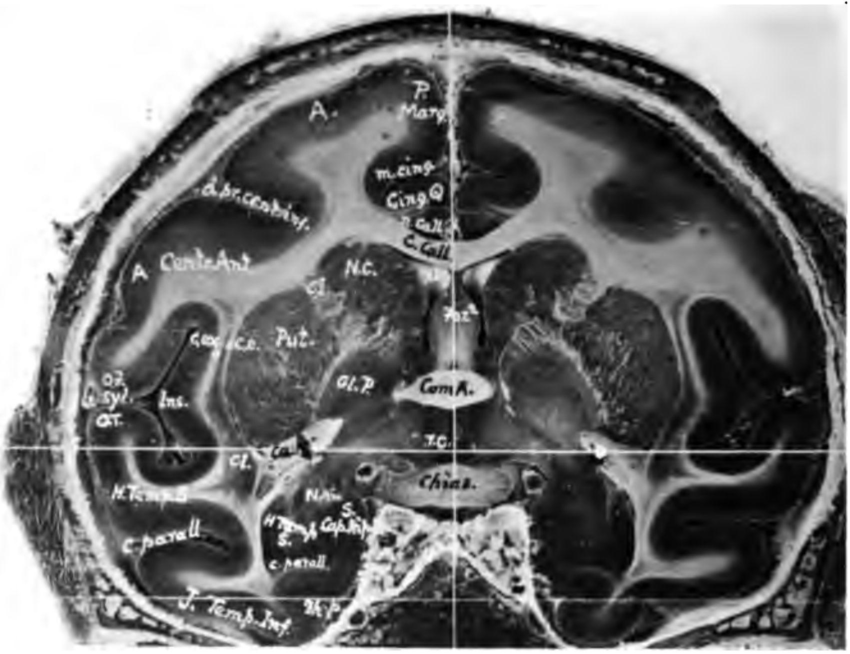
ANTERIOR FRONTAL LAMELLA. XV.



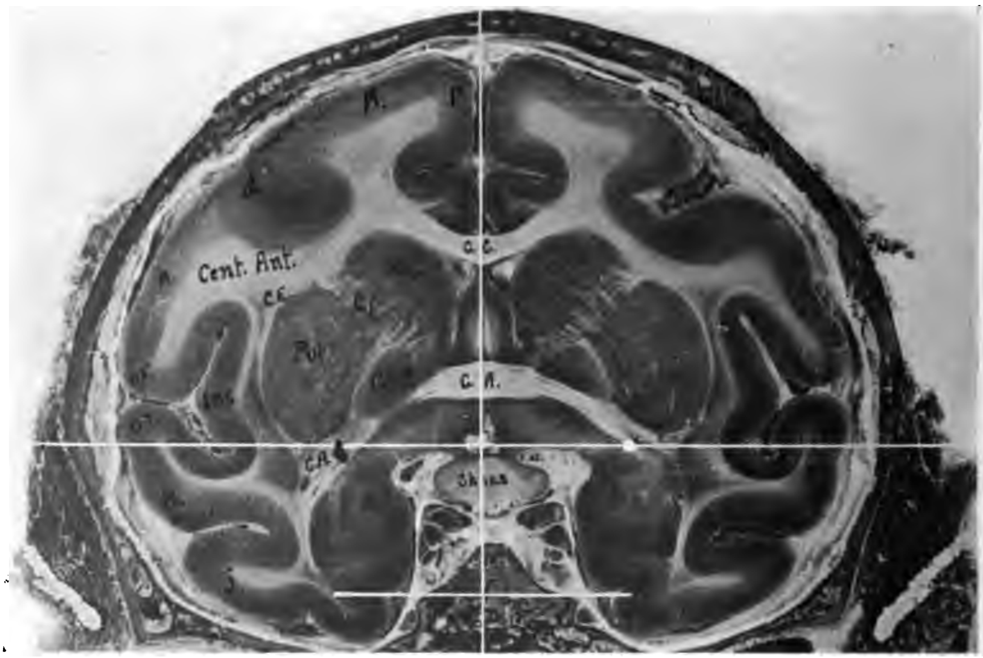
Anterior Frontal Lamella. XVI.



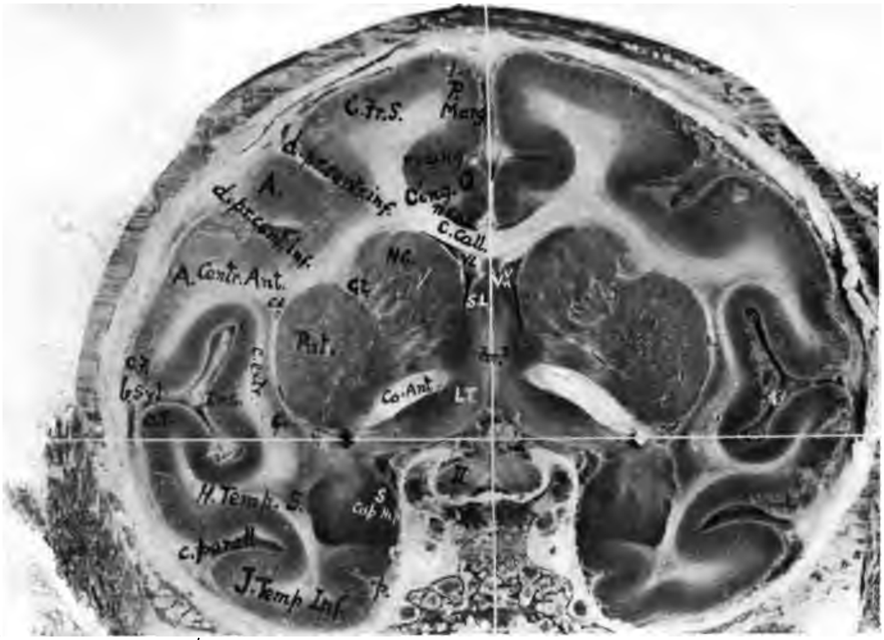
Anterior Frontal Lamella. XVI.



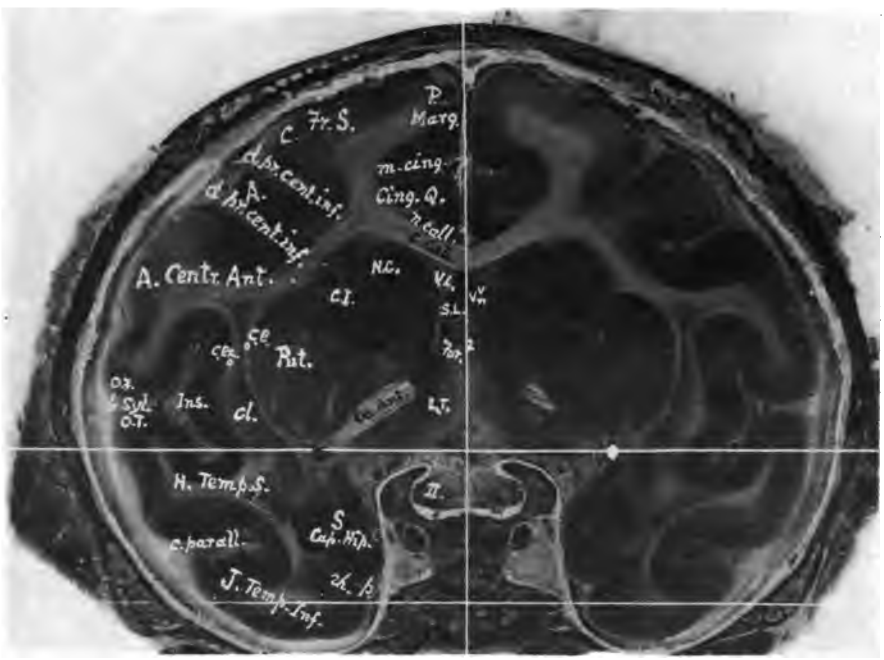
ANTERIOR FRONTAL LAMELLA. XVII.



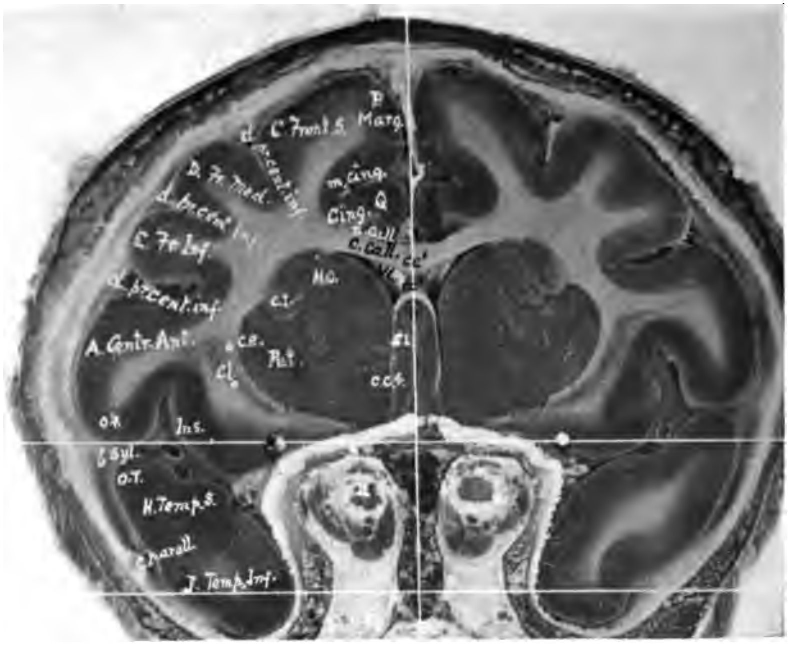
ANTERIOR FRONTAL LAMELLA. XVIII.



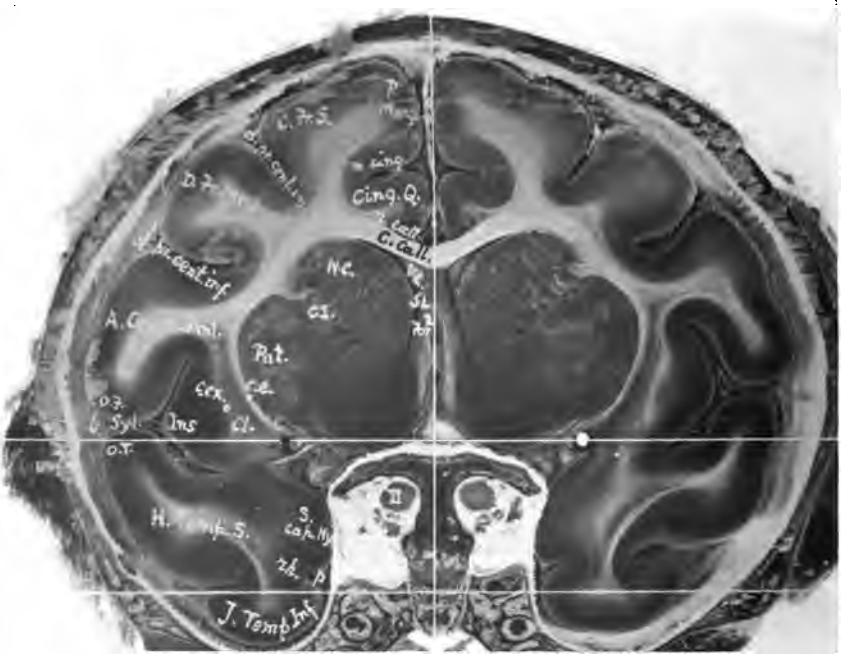
ANTERIOR FRONTAL LAMELLA. XIX.



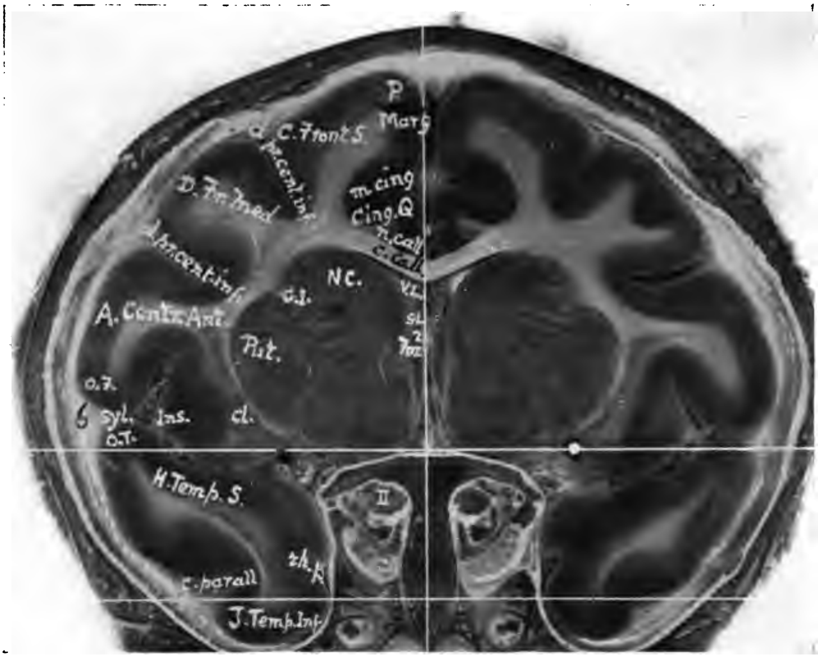
ANTERIOR FRONTAL LAMELLA. XX.



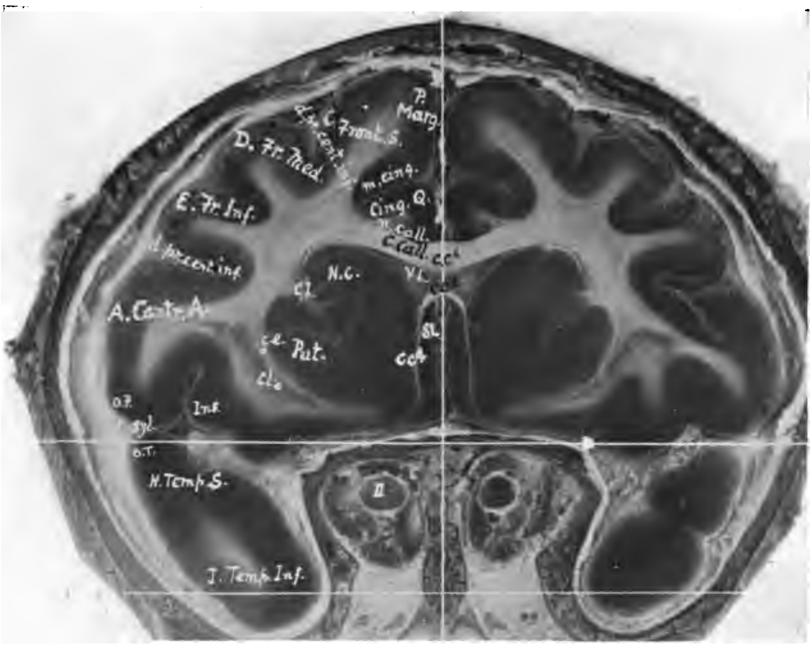
ANTERIOR FRONTAL LAMELLA. XXI.



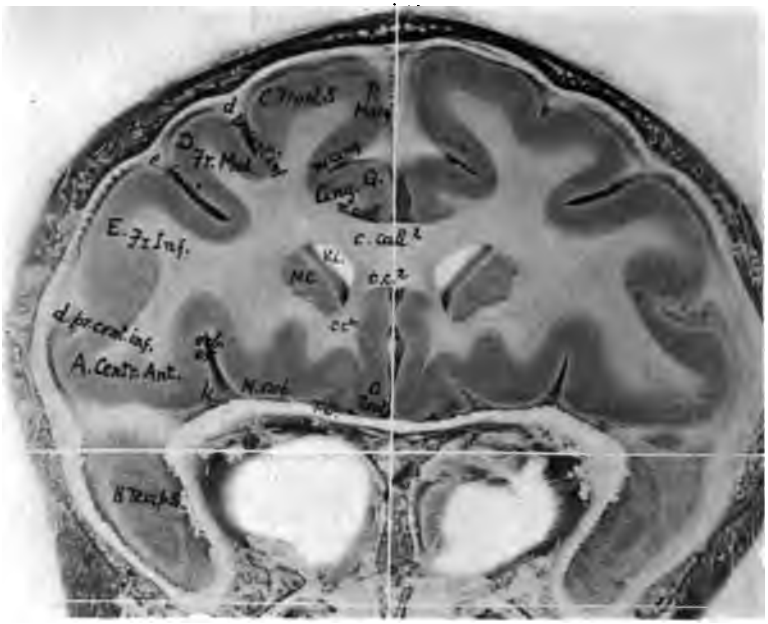
ANTERIOR FRONTAL LAMELLA. XXII.



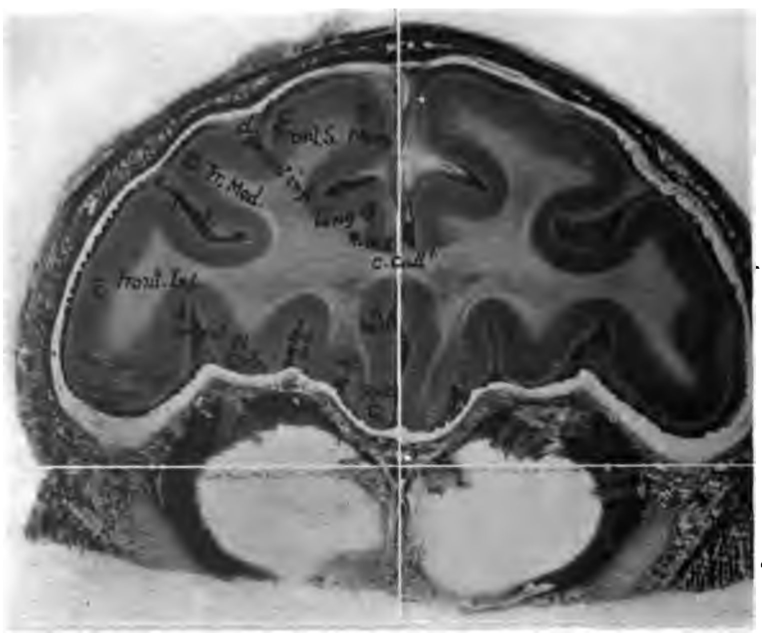
ANTERIOR FRONTAL LAMELLA. XXIII.



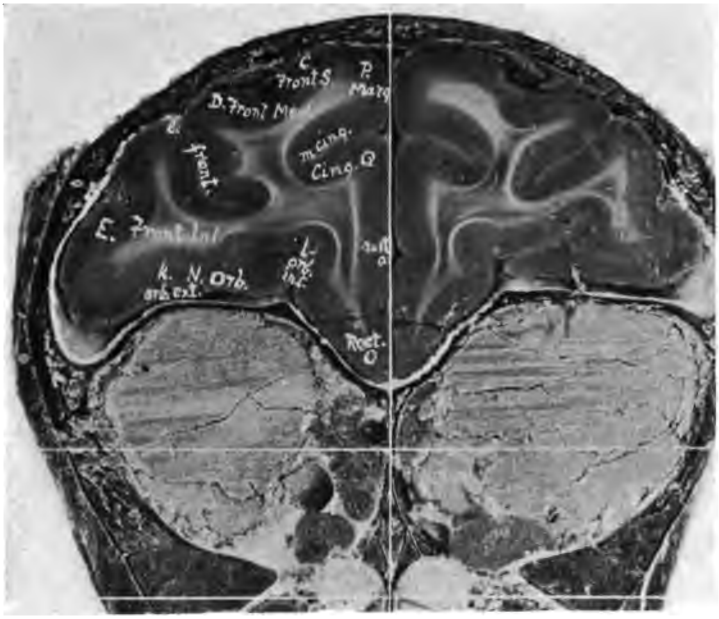
ANTERIOR FRONTAL LAMELLA. XXIV.



ANTERIOR FRONTAL LAMELLA. XXVI.



ANTERIOR FRONTAL LAMELLA. XXVIII.

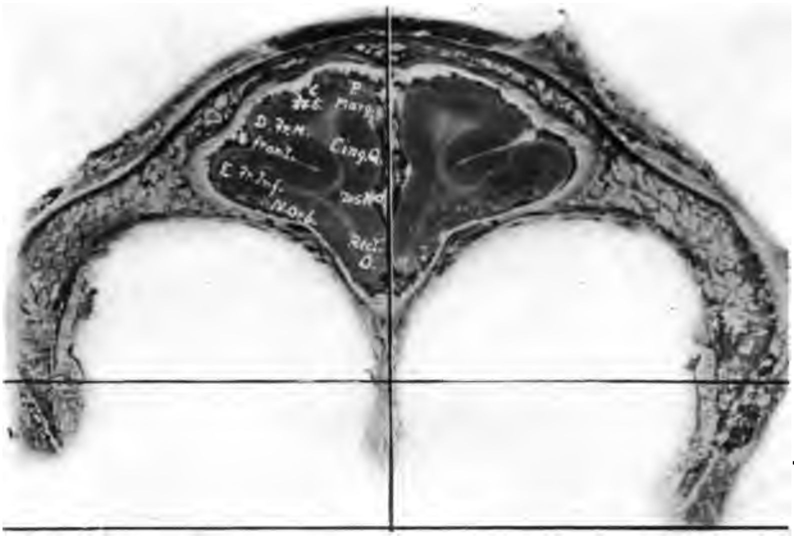


ANTERIOR FRONTAL LAMELLA. XXX.

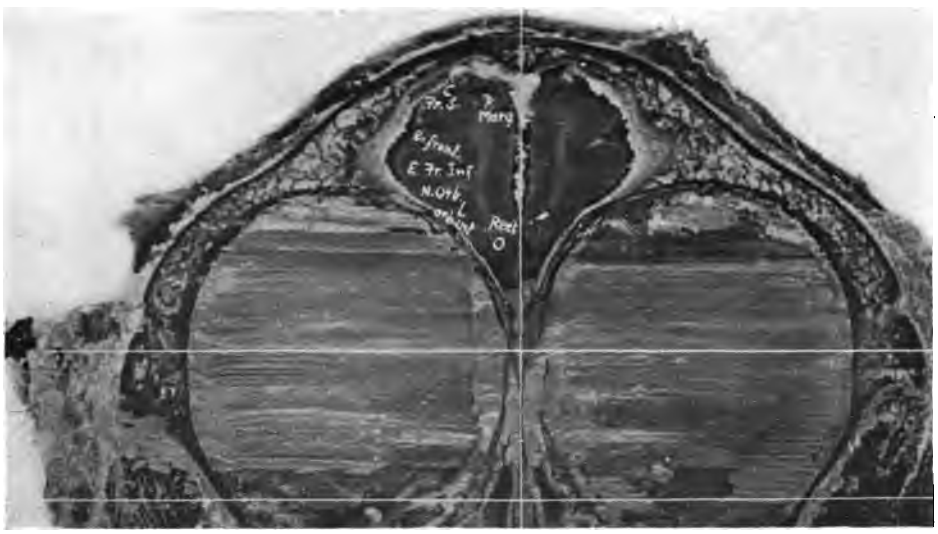
ANTERIOR FRONTAL LAMELLA. XXXII.

ANTERIOR FRONTAL LAMELLA. XXXIV.

ANTERIOR FRONTAL LAMELLA. XXXVI.



ANTERIOR FRONTAL LAMELLA. XXXVIII.



ANTERIOR FRONTAL LAMELLA. XL.

poster-

dialis.
rior.

uperfi-

elli.

GYRI. (Capital letters)

B. **Gyrus centralis posterior.**
F. **Gyrus angularis.**
G. **Gyrus postparietalis.**
H. **Gyrus temporalis posterior.**
M. **Gyrus occipitalis inferior.**
P. **Gyrus marginalis.**
Q. **Gyrus cingulatus.**
R. **Gyrus hippocampi.**
V. **Gyrus cuneatus.**
W. **Gyrus precuneatus.**

SULCI. (Small letters)

b. **Sulcus sylvianus.**
c. **Sulcus parallel.**
f. **Sulcus intraparietalis.**
h. **Sulcus occipito-temporalis.**
j. **Sulcus occipitalis inferior.**
m. **Sulcus cinguli.**
n. **Sulcus corporis callosi.**
q. **Sulcus calcarinus.**
s. **Sulcus collateralis.**
u. **Sulcus postcentralis.**
v. **Sulcus subparietalis.**
x. **Sulcus hippocampi.**

POST

CE

1. Lin
2. Lob
10. Lob
11. Lob
13. Lob
13¹. Par tr
14. Lob
16. Fiss
18. Fiss
19. Fiss

NE

V². R
VI¹. N
VIII¹. N
IX. N
IX¹. N
X. N
X¹. N

MOR FRONTAL LAMELLÆ. III—I

BELLUM. (Numerals)

osterior. .a.

:us centralis.

lis. :us paramesialis.

posterior. :us pennatus anterior.

nferior. :us paraflocculus.

:cculus, processus lateralis (pe-
l lobule).

:us flocculus.

:a precentralis.

:a preclivalis.

:a postclivalis.

'I. (Roman numerals)

:ix spinalis nervi trigemini.

:leus nervi abducentis.

:leus dorsalis nervi acustici.

alis. :vus glossopharyngeus.

rior. :leus nervi glosso-pharyngei.

:vus vagus.

:leus dorsalis nervi vagi.

ABBREVIATIONS

C. A.	Cornu ammonis.
C. Call².	Corpus callosum (splenium).
C. Q. A.	Colliculus superior.
C. Q. P.	Colliculus inferior.
Ep.	Epiphysis.
E. T.	Eminentia medialis (teres).
Fl.	Fasciculus spino-cerebellaris posterior (Flechsig).
F. l. d.	Fasciculus longitudinalis medialis.
F l. i.	Fasciculus longitudinalis inferior.
F. p. d.	Fasciculus predorsalis.
Go.	Fasciculus antero-lateralis superficialis (Gowers).
L. c.	Locus ceruleus.
L. M.	Lemniscus medialis.
N. B.	Nucleus Becterew.
N. C.¹	Nucleus caudatus (cauda).
N. D.	Nucleus Deiters.
O. i.	Oliva inferior.
P. c. i.	Corpus restiforme.
P. c. m.	Brachium pontis.
P. c. s.	Brachium conjunctivum cerebelli.
Py¹.	Tractus pyramidalis.
R. O.	Radiatio occipito-thalamica.
R. sp.	Tractus rubro-spinalis.
S. g.	Substantia gelatinosa.
T. Ac.	Tuberculum acusticum.
Tap.	Tapetum.
T. sp.	Tractus tecto-spinalis.
V. L.	Ventriculus lateralis.
Vn. iv.	Ventriculus quartus.

ɪs

·is poster-

medialis.
n ferior.

superfi-

ɪis.

ɪrebelli.

ɪ.

POSTERIO

GYRI. (Capital letters)

B. Gyrus centralis posterior.
F. Gyrus angularis.
G. Gyrus postparietalis.
H. Gyrus temporalis superior.
K. Gyrus occipito-temporalis.
L. Gyrus occipitalis superior.
M. Gyrus occipitalis inferior.
P. Gyrus marginalis.
T. Gyrus lingualis.
V. Gyrus cuneatus.
W. Gyrus precuneatus.

SULCI. (Small letters)

b. Sulcus sylvianus.
c. Sulcus parallel.
f. Sulcus intraparietalis.
g. Sulcus parieto-occipitalis externus.
h. Sulcus occipito-temporalis.
i. Sulcus occipitalis lateralis.
j. Sulcus occipitalis inferior.
m. Sulcus cinguli.
q. Sulcus calcarinus.
r. Sulcus parieto-occipitalis internus.
s. Sulcus collateralis.
v. Sulcus subparietalis.

CE

2. Lobu
3. Lobul
4. Lobu
5. Foliu
6. Tube
7. Pyra
8. Uvula
9. Nodu
10. Lobu
11. Lobul
12. Lobul
13. Paraf
13^1. Paraf
18. Fissu
19. Fissu
20. Fissu
21. Fissu
22. Fissu
23. Fissu
27. Fissu
28. Fissu
38. Nucle
39. Nucle
40. Nucle
41. Nucle

NE

V^2. Ra
$VIII^1$. Nu
IX. Ne
X. Ne
X^1. Nu
X^1. Tra
XI. Ne
XII. Ne
XII^1. Nu

[illegible]R FRONTAL LAMELLÆ. XXV—IV

[illegible]REBELLUM. (Numerals)

[illegible]lus centralis.
[illegible]lus culminis.
[illegible]lus clivi.
[illegible]m vermis.
[illegible]r vermis.
[illegible]mis.
[illegible]
[illegible]lus.
[illegible]lus paramesialis.
[illegible]lus pennatus anterior.
[illegible]lus pennatus posterior.
[illegible]locculus.
[illegible]locculus processus lateralis.
[illegible]ura preclivalis.
[illegible]ura postclivalis.
[illegible]ura horizontalis.
[illegible]ura postpyramidalis.
[illegible]ura prepyramidalis.
[illegible]ura postnodularis.
[illegible]ura paramesialis internus.
[illegible]ura paramesialis externus.
[illegible]eus fastigii.
[illegible]eus globosus.
[illegible]eus emboliformis.
[illegible]eus dentatus.

[illegible]ERVI. (Roman numerals)

[illegible]dix spinalis nervi trigemini.
[illegible]cleus dorsalis nervi acustici.
[illegible]rvus glosso-pharyngeus.
[illegible]rvus vagus.
[illegible]cleus dorsalis nervi vagi.
[illegible]ractus solitarius nervi vagi.
[illegible]ervus accessorius.
[illegible]ervus hypoglossus.
[illegible]cleus dorsalis nervi hypoglossi.

INITIALS and ABBREVIATIONS

Com. Cb.	Commissura cerebelli.
C. P.	Cornu posterius.
C. R.	Corpus restiforme.
Dec. L.	Decussatio lemniscorum.
F. B. / F. Cu.	Funiculus cuneatus.
F. G.	Funiculus gracilis.
Fl.	Fasciculus spino-cerebellaris posterior (Flechsig).
F. lat.	Funiculus lateralis.
F. l. d.	Fasciculus longitudinalis medialis.
F. l. i.	Fasciculus longitudinalis inferior.
F. p.	Funiculus posterior.
F. p. d.	Fasciculus predorsalis.
Go.	Fasciculus antero-lateralis superficialis (Gowers).
N. C. R.	Nucleus corporis restiformis.
N. Cu.	Nucleus funiculi cuneati.
P. c. s.	Brachium conjunctivum cerebelli.
Py.[1]	Tractus pyramidalis.
Py.[1] X.	Decussatio pyramidum.
R. O.	Radiatio occipito-thalamica.
R. sp.	Tractus rubro-spinalis.
S. G.	Substantia gelatinosa.
S. R.	Substantia Rolandi.
Tap.	Tapetum.
T. so.	Tractus solitarius.
V. L.	Ventriculus lateralis.
Vn. iv.	Ventriculus quartus.

lateralis superfi-

ı.
is, nucleus dor-

ı, nucleus media-

, nucleus ventra-

ı.

caput.
cauda.

gmenti.
griseæ centralis.
egmenti.

vum cerebelli.

alamica.
lis.

ı.

GYRI. (Capital letters)

B. Gyrus centralis posterior.
F. Gyrus angularis.
G. Gyrus postparietalis.
H. Gyrus temporalis superior.
K. Gyrus occipito-temporalis.
M. Gyrus occipitalis inferior.
P. Gyrus marginalis.
Q. Gyrus cingulatus.
R. Gyrus hippocampi.

SULCI. (Small letters)

b. Sulcus sylvianus.
c. Sulcus parallel.
f. Sulcus intraparietalis.
h. Sulcus occipito-temporalis.
j. Sulcus occipitalis inferior.
m. Sulcus cinguli.
n. Sulcus corporis callosi.
u. Sulcus postcentralis.
x. Sulcus hippocampi.

CEREBELLUM. (Numerals)

1. Lingula.
2. Lobulus centralis.
11. Lobulus pennatus anterior.
13. Paraflocculus.
13^1. Paraflocculus, processus lateralis (petrosal lobule).
14. Flocculus.

ANTE

IV^2. Nucle
IV^3. Decus
V^1. Radix
V^2. Radix
V^3. Nucle
V^4. Nucle
V^5. Nucle
V^6. Nucle
VI. Nucle
VII. Nervu
VII^2. Genu
VIII. Nervu

Alv. Alve
Aq. Aqua
Br. A. Brac
Br. P. Brac
C. A. Corn
C. $Call^2$. Corp
C. I. Caps
C. Q. A. Colli
C. Q. P. Colli
Co. Q. P. Comr ior
Ep. Epipl
E. T. Emin
Fi. Fimb
F. l. d. Fasci
F. l. i. Fasci
For. Forn
For^1. Forn
For^3. Forn
For^5. Forn
G. D. Gyru
Gl. Pi. Glan

MOR FRONTAL LAMELLÆ. I—III

ERVI. (Roman numerals)

us nervi trochlearis.
atio nervorum trochlearium.
mesencephalicus trigemini.
spinalis nervi trigemini.
us mesencephalicus nervi trigemini.
us motor minor nervi trigemini.
us motor major nervi trigemini.
us sensilis nervi trigemini.
us nervi abducentis.
s facialis.
nervi facialis.
s acusticus.

ABBREVIATIONS

s.
ductus sylvii.
ium anticum.
ium posticum.
ammonis.
s callosum (splenium).
la interna.
ulus superior.
ulus inferior.
nissura colliculorum inferum.
ysis.
entia medialis (teres).
ia fornicis.
culus longitudinalis medialis.
culus longitudinalis inferior.
x.
x, columna horizontalis.
x, fimbria.
x, columna posterior.
dentatus.
ula pinealis.

Go.	Fasciculus antero-lateralis superficialis (Gowers).
Gr. C.	Grisea centralis.
Hab.	Habenula.
Lin. inter.	Linea interauralis.
L. C.	Locus ceruleus.
L. L.	Lemniscus lateralis.
L. L. n. d.	Lemniscus lateralis, nucleus dorsalis.
L. L. n. m.	Lemniscus lateralis, nucleus medialis.
L. L. n. v.	Lemniscus lateralis, nucleus ventralis.
L. M.	Lemniscus medialis.
N. B.	Nucleus Becterew.
N. C.	Nucleus caudatus, caput.
N. C¹.	Nucleus caudatus, cauda.
N. D.	Nucleus Deiters.
N. D. T.	Nucleus dorsalis tegmenti.
N. V. gr.	Nucleus ventralis griseæ centralis.
N. V. T.	Nucleus ventralis tegmenti.
O. acc.	Oliva accesoria.
Oi.	Oliva inferior.
P. c. i.	Corpus restiforme.
P. c. m.	Brachium pontis.
P. c. s.	Brachium conjunctivum cerebelli.
Pulv.	Pulvinar.
Pul. l.	Pulvinar lateralis.
Pul. m.	Pulvinar medialis.
R. O.	Radiatio occipito-thalamica.
R. sp.	Tractus rubro-spinalis.
Str. t.	Stria terminalis.
Str. z.	Stratum zonale.
Sub.	Subiculum.
Tap.	Tapetum.
V. L.	Ventriculus lateralis.

4

ıcleus dor-

eus medius.
ʼeus ventra-

na.
t).
a).
i.
ıi.
ti.
ni.
nti.

cerebelli.

ica.

nti.

ANTERI(

GYRI. (Capital letters)

A. Gyrus centralis anterior.
B. Gyrus centralis posterior.
F. Gyrus angularis.
H. Gyrus temporalis superior.
J. Gyrus temporalis inferior.
K. Gyrus occipito-temporalis.
P. Gyrus marginalis.
Q. Gyrus cingulatus.
R. Gyrus hippocampi.

SULCI. (Small letters)

a. Sulcus centralis
b. Sulcus sylvianus.
c. Sulcus parallel.
f. Sulcus intraparietalis.
h. Sulcus occipito-temporalis.
m. Sulcus cinguli.
n. Sulcus corporis callosi.
u. Sulcus postcentralis.
x. Sulcus hippocampi.

CEREBELLUM. (Numerals)

14. Flocculus.

NERVI. (R

IV^1. Nu. IV. } Nucleus
V. N. V. } Nervus t
V^2. Nucleus me
V^3. Nucleus m
VIII. Nervus a

ABE

Alv. Alveus.
Aq. Aqueduct
Br. A. Brachiur
Br. P. Brachiur
C. A. Cornu a
C. Call. Corpus c
C. Call². Corpus c
C. G. E. Corpus g
C. G. I. Corpus g
C. I. Capsula
Co. Po. Commiss
C. Q. A. Colliculu
C. Q. P. Colliculu
Dec. Br. Decussat vorum.
Ep. Epiphysi
F. l. d. Fascicul
F. l. i. Fascicul
Flo. Flocculu
For. Fornix.
For¹. Fornix,
For². Fornix, f
G. D. Gyrus d
G. Hab. Ganglio

...R FRONTAL LAMELLÆ. IV—VI

(...man numerals)

...nervi trochlearis.

...trigeminus.

...mesencephalicus nervi trigemini.

...motor major nervi trigemini.

...acusticus.

...BREVIATIONS

...s.

...uctus sylvii.

...ium anticum.

...hium posticum.

...u ammonis.

...us callosum.

...us callosum, splenium.

...us geniculatum externum.

...us geniculatum internum.

...ula interna.

...missura posterior.

...iculus superior.

...iculus inferior.

...ussatio brachiorum conjunctivorum.

...physis.

...ciculus longitudinalis medialis.

...ciculus longitudinalis inferior.

...cculus cerebelli.

...rnix.

...rnix, columna horizontalis.

...rnix, fimbria.

...rus dentatus.

...nglion habenulæ.

Gr. C.	Grisea centralis.
Hab.	Habenula.
L. L.	Lemniscus lateralis.
L. L. n. d.	Lemniscus lateralis, nucleus dorsalis.
L. L. n. m.	Lemniscus lateralis, nucleus medius.
L. L. n. v.	Lemniscus lateralis, nucleus ventralis.
L. M.	Lemniscus medialis.
L. m. e.	Lamina medullaris externa.
N. C.	Nucleus caudatus (caput).
N. C.[1]	Nucleus caudatus (cauda).
N. L.	Nucleus lateralis thalami.
N. M.	Nucleus medialis thalami.
N. D. T.	Nucleus dorsalis tegmenti.
N. V.	Nucleus ventralis thalami.
N. V. T.	Nucleus ventralis tegmenti.
O. I.	Oliva inferior.
P. c. m.	Brachium pontis.
P. c. s.	Brachium conjunctivum cerebelli.
Pl. ch.	Plexus choroideus.
Pul.	Pulvinar.
Py.[1]	Tractus pyramidalis.
R. O.	Radiatio occipito-thalamica.
Str. t.	Stria terminalis.
Str. z.	Stratum zonale thalami.
Sub.	Subiculum.
Tap.	Tapetum.
Tr. Cent. Teg.	Tractus centralis tegmenti.
V. L.	Ventriculus lateralis.
Vn.[III]	Ventriculus tertius.
Z. r.	Zona recticularis.

5

nalis me-

ıalami.

mi.
ami.

a.

ıillaris

ANTERIOR

GYRI. (Capital letters)

A. Gyrus centralis anterior.
B. Gyrus centralis posterior.
H. Gyrus temporalis superior.
J. Gyrus temporalis inferior.
K. Gyrus occipito-temporalis.
P. Gyrus marginalis.
Q. Gyrus cingulatus.
R. Gyrus hippocampi.
S. Gyrus hippocampi (caput).
U. Gyrus uncinatus.

SULCI. (Small letters)

a. Sulcus centralis
b. Sulcus sylvianus.
c. Sulcus parallel.
f. Sulcus intraparietalis.
h. Sulcus occipito-temporalis.
m. Sulcus cinguli.
n. Sulcus corporis callosi.
p. Sulcus rhinalis.
t. Sulcus precentralis superior.
x. Sulcus fissura hippocampi.

NERVI. (Roman numerals)

II^1. Tractus opticus.
III^1. Nucleus nervi oculo-motorii.
V. Nervus trigeminus.

Alv. Alve
C. A. Corn
C. Call. Corp
C. e. Caps
C. ext. Caps
C. G. E. Corp
C. G. I. Corp
C. I. Caps
Cl. Claustr
C. M. Centr
C. Mam. Corp
Com. A. Com
Com. M. Mass
C. Sth. Corp
F. l. i. Fasc
F. M. Fasc
For. Forn
For^1. Forn
For^2. Forn
For^3. Forn
For^4. Forn
G. D. Gyr
G. H. Gan
G. P. / Gl. P. Glob
Hab. Hab
Hyp^1. Hyp
Hyp^2. Hyp
Hyp^3. Hyp
Inf. Inf
Ins. Ins
L. m. e. Lam
L. m. i. Lam
L. m. v. Lam
L. N. Loc
N. A. Nuc

5

FRONTAL LAMELLÆ. VII—XVI

3REVIATIONS

s.
. ammonis.
s callosum.
.la externa.
.la extrema.
.s geniculatum externum.
ıs geniculatum internum.
ıla interna.
:trum.
e médian (Luys').
ıs mammillare.
nissura anterior.
a intermedia.
us subthalamicum.
iculus longitudinalis inferior.
lculus retroflexus (Meynert).
ıix.
ıix, columna horizontalis.
ıix, columnæ anteriores.
ıix, fimbria.
aix, nucleus proprius.
us dentatus.
glion habenulæ.
ous pallidus.
enula.
ophysis, pars anterior.
ophysis, pars posterior.
ophysis, pars intermedia.
ndibulum.
la.
ina medullaris externa.
ina medullaris interna.
ina medullaris ventralis.
s niger.
eus anterior thalami.

N. Am. Nucleus amygdalæ.
N. C. Nucleus caudatus (caput).
N. C. l. Nucleus caudatus (cauda).
N. f. l. d. Nucleus fasciculi longitudinalis medialis.
N. I. Nucleus interpeduncularis.
N. L. Nucleus lateralis thalami.
N. M. Nucleus medialis thalami.
N. Pf. Nucleus parafascicularis thalami.
N. Po. Nuclei pontis.
N. R. Nucleus ruber.
N. Sl. Nucleus semilunaris thalami.
N. Sm. Nucleus submedianus thalami.
N. V. Nucleus ventralis thalami.
O. F. Operculum frontale.
O. T. Operculum temporale.
P. c. Pedunculus cerebri.
P. c. m. Brachium pontis.
Pons. Pons Varolii.
P. P. C. Pes pedunculi cerebri.
Pulv. Pulvinar thalami.
Put. Putamen.
R. O. Radiatio occipito-thalamica.
Srt. Substantia reticularis.
Str. t. Stria terminalis.
Sub. Subiculum.
Tap. Tapetum.
T. th. Taenia thalami.
V. A. Fasciculus thalamo-mammillaris (Vicq d'Azyr).
V. L. Ventriculus lateralis.
Vn. III. Ventriculus tertius.
Vn. V. Ventriculus quintus.
Z. i. Zona incerta.
Z. r Zona reticularis.

ANTERI(

GYRI. (Capital lette

A. Gyrus centralis ant
C. Gyrus frontalis sup
D. Gyrus frontalis med
E. Gyrus frontalis infe
H. Gyrus temporalis su
J. Gyrus temporalis in
N. Gyrus orbitalis.
O. Gyrus rectus.
P. Gyrus marginalis.
Q. Gyrus cingulatus.
S. Gyrus hippocampi (

SULCI. (Small lette

a. Sulcus centralis
b. Sulcus sylvianus.
c. Sulcus parallel.
d. Sulcus precentralis
e. Sulcus frontalis.
k. Sulcus orbitalis ext
l. Sulcus orbitalis inte
m. Sulcus cinguli.
n. Sulcus corporis call
o. Sulcus rostralis.
p. Sulcus rhinalis.
w. Sulcus olfactorius.

NERVI. (Roman num

I. Nervus olfactorius.
II. Nervus opticus.
II^2. Chiasma.

TERIOR FRONTAL LAMELLÆ. XVII—XL

tal letters)		ABBREVIATIONS
lis anterior.	C. Call.	Corpus callosum.
lis superior.	C. Call[1].	Corpus callosum, genu.
lis medius.	C. Call[2].	Corpus callosum, splenium.
is inferior.	C. Call[3].	Corpus callosum, rostrum.
alis superior.	C. Call[4].	Corpus callosum, columnæ.
alis inferior.	C. E.	Capsula externa.
is.	Chias.	Chiasma.
	C. I.	Capsula interna.
alis.	Cl.	Claustrum.
atus.	Com. A.	Commissura anterior.
ampi (caput).	For[2].	Fornix, columnæ anteriores.
	Gl. p.	Globus pallidus.
ll letters)	Ins.	Insula.
lis	L. T.	Lamina terminalis.
ius.	N. Am.	Nucleus amygdalæ.
l.	N. C.	Nucleus caudatus (caput).
tralis inferior.	O. F.	Operculum frontale.
is.	O. T.	Operculum temporale.
is externus.	Put.	Putamen.
is internus.	S. L.	Septum pellucidum.
.	T. C.	Tuber cinereum.
is callosi.	T. O.	Trigonum olfactorium.
ls.	V. L.	Ventriculus lateralis.
a.	Vn. V.	Ventriculus quintus.
rius.		

n numerals)

orius.

s.

INDEX

CEREBRUM

	GYRI. (Capital letters)	ABBREVIATIONS
A.	Gyrus centralis anterior.	Cent. A.
B.	Gyrus centralis posterior.	Cent. P.
C.	Gyrus frontalis superior.	Front. S.
D.	Gyrus frontalis medius.	Front. M.
E.	Gyrus frontalis inferior.	Front. I.
F.	Gyrus angularis.	Ang.
G.	Gyrus postparietalis.	Po. par.
H.	Gyrus temporalis superior.	Temp. S.
J.	Gyrus temporalis inferior.	Temp. I.
K.	Gyrus occipito-temporalis.	Occ. T.
L.	Gyrus occipitalis superior.	Occ. S.
M.	Gyrus occipitalis inferior.	Occ. I.
N.	Gyrus orbitalis.	Orb.
O.	Gyrus rectus.	Rect.
P.	Gyrus marginalis.	Marg.
Q.	Gyrus callosus.	Call.
R.	Gyrus hippocampi.	Hip.
S.	Gyrus hippocampi (caput).	Cap. Hip.
T.	Gyrus lingualis.	Ling.
U.	Gyrus uncinaus.	Un.
V.	Gyrus cuneatus.	Cun.
W.	Gyrus precuneatus.	Pr. C.

	SULCI. (Small letters)	ABBREVIATIONS
a.	Sulcus centralis.	Cent.
b.	Sulcus sylvianus.	Syl.
c.	Sulcus parallel.	Parall.
d.	Sulcus precentralis inferior.	Pr. inf.
e.	Sulcus frontalis.	Fr.
f.	Sulcus intraparietalis.	Intr. p.
g.	Sulcus parieto-occipitalis externus.	P. occ. ex.
h.	Sulcus occipito-temporalis.	Occ. t.
i.	Sulcus occipitalis lateralis.	Occ. lat.
j.	Sulcus occipitalis inferior.	Occ. inf.
k.	Sulcus orbitalis externus.	Or. ex.
l.	Sulcus orbitalis internus.	Or. int.

m.	Sulcus cinguli.	Cing.
n.	Sulcus callosus.	Call.
o.	Sulcus rostralis.	Ros.
p.	Sulcus rhinalis.	Rh.
q.	Sulcus calcarinus.	Calc.
r.	Sulcus parieto-occipitalis internus.	P. occ. int.
s.	Sulcus collateralis.	Coll.
t.	Sulcus precentralis superior.	Pr. c. s.
u.	Sulcus postcentralis.	Po. c.
v.	Sulcus subparietalis.	Sub. par.
w.	Sulcus olfactorius.	Olf.
x.	Fissura hippocampi.	Hip.

	LOBULI. (Numerals)	ABBREVIATIONS
1.	Lingula.	Ling.
2.	Lobulus centralis.	Cent.
3.	Lobulus culminis.	Cul.
4.	Lobulus clivi.	Cliv.
5.	Folium vermis.	Fol.
6.	Tuber vermis.	Tub.
7.	Pyramis.	Py.
8.	Uvula.	Uv.
9.	Nodulus.	Nod.
10.	Lobulus paramesialis.	Par. mes.
11.	Lobulus pennatus anterior.	Pen. A.
12.	Lobulus pennatus posterior.	Pen. P.
13.	Paraflocculus.	Pfl.
13[1].	Paraflocculus, processus lateralis (petrosal lobule).	Pfl. p. l.
14.	Flocculus.	Fl.

	SULCI	ABBREVIATIONS
16.	Sulcus precentralis.	Pr. c.
17.	Sulcus postcentralis.	Po. c.
18.	Sulcus preclivalis (fissura prima).	Pr. cl.
19.	Sulcus postclivalis (rachis pennæ).	Po. cl.
20.	Sulcus horizontalis.	Hor.
21.	Sulcus postpyramidalis.	Po. py.
22.	Sulcus prepyramidalis.	Pr. py.
23.	Sulcus post nodularis.	Po. nod.
24.	Sulcus paraflocculi superior.	Pfl. s.
25.	Sulcus paraflocculi inferior.	Pfl. i.
27.	Sulcus paramesialis internus.	Pm. i.
28.	Sulcus paramesialis externus.	Pm. e.

CRANIAL NERVES. (Roman numerals)

I.	Nervus olfactorius.
I^1.	Tractus nervi olfactorii.
II.	Nervus opticus.
II^1.	Tractus nervi optici.
II^2.	Chiasma nervorum opticorum.
III.	Nervus oculomotor.
III^1.	Nucleus nervi oculomotoris.
IV.	Nervus trochlearis.
IV^1.	Nucleus nervi trochlearis.
IV^2.	Decussatio nervorum trochlearium.
V.	Nervus trigeminus.
V^1.	Radix mesencephalicus nervi trigemini.
V^2.	Radix spinalis nervi trigemini.
V^3.	Nucleus mesencephalicus nervi trigemini.
V^4.	Nucleus motor minor nervi trigemini.
V^5.	Nucleus motor major nervi trigemini.
V^6.	Nucleus sensilis nervi trigemini.
VI.	Nervus abducens.
VI^1.	Nucleus nervi abducentis.
VII.	Nervus facialis.
VII^1.	Radix nervi facialis.
VII^2.	Genu nervi facialis.
VII^3.	Nucleus nervi facialis.
VIII.	Nervus acusticus.
$VIII^1$.	Nucleus dorsalis nervi acustici.
$VIII^2$.	(N. D.) Nucleus Deiters.
$VIII^3$.	(N. B.) Nucleus Bechterew.
$VIII^4$.	Tuberculum acusticum (Tub. Ac.).
IX.	Nervus glossopharyngeus.
IX^1.	Nucleus nervi glossopharyngei.
X.	Nervus vagus.
X^1.	Nucleus dorsalis nervi vagi.
X^2.	Tractus solitarius nervi vagi.
X^3.	Nucleus ambiguus nervi vagi.
XI.	Nervus accessorius.
XI^1.	Nucleus nervi accessorii.
XII.	Nervus hypoglossus.
XII^1.	Nucleus nervi hypoglossi.

ABBREVIATIONS

Al.	Alveus.
Aq.	Aqueductus cerebri.
Br. A.	Brachium anticum.
Br. P.	Brachium posticum.
C. A.	Cornu ammonis.

C. Call.	Corpus callosum.
C. Call^{1}.	Corpus callosum, genu.
C. Call^{2}.	Corpus callosum, splenium.
C. Call^{3}.	Corpus callosum, rostrum.
C. Call^{4}.	Corpus callosum, columnæ.
C. e.	Capsula externa.
C. ex.	Capsula extrema.
C. G. E.	Corpus geniculatum externum.
C. G. I.	Corpus geniculatum internum.
Chias.	Chiasma.
Cl.	Claustrum.
C. M.	Centre médian (Luys').
C. Mam.	Corpus mammillare.
Com. A.	Commissura anterior.
Com. Cb.	Commissura cerebelli.
Co. m. M.	Massa intermedia.
Co. Po.	Commissura posterior.
Co. CQP.	Commissura colliculi inferioris.
C. P.	Cornu posterius.
C. Q. A.	Colliculus superior.
C. Q. P.	Colliculus inferior.
C. R.	Corpus restiforme.
C. Sth.	Corpus subthalamicum.
Dec. Br.	Decussatio brachiorum conjunctivorum.
Dec. L.	Decussatio lemniscorum.
Ep.	Epiphysis.
E. T.	Eminentia medialis (teres).
F. B. F. Cu.	Fasciculus cuneatus.
F. G.	Fasciculus gracilis.
Fl.	Fasciculus spino-cerebellaris posterior (Flechsig).
F. lat.	Funiculus lateralis.
F. l. d.	Fasciculus longitudinalis medialis.
F. l. i.	Fasciculus longitudinalis inferior.
Flo.	Flocculus.
F. M.	Fasciculus retroflexus (Meynert).
For.	Fornix.
For^{1}.	Fornix, columnæ horizontales.
For^{2}.	Fornix, columnæ anteriores.
For^{3}.	Fornix, fimbria.
For^{4}.	Fornix, nucleus proprius.
For^{5}.	Fornix, columnæ posteriores.
F. p.	Funiculus posterior.
F. p. d.	Fasciculus predorsalis.
G. D.	Gyrus dentatus.

G. Hab.	Ganglion habenulæ.
G. P. Gl. P.	Globus pallidus.
G. Pi.	Glandula pinealis.
Go.	Fasciculus anterolateralis superficialis (Gowers).
Gr. C.	Grisea centralis.
Hab.	Habenula.
Hyp^1.	Hypophysis pars anterior.
Hyp^2.	Hypophysis pars posterior.
Hyp^3.	Hypophysis pars medialis.
Inf.	Infundibulum.
Ins.	Insula.
L. C.	Locus ceruleus.
L. L.	Lemniscus lateralis.
L. L. n. d.	Lemniscus lateralis, nucleus dorsalis.
L. L. n. m.	Lemniscus lateralis, nucleus medius.
L. L. n. v.	Lemniscus lateralis, nucleus ventralis.
L. M.	Lemniscus medialis.
L. m. e.	Lamina medullaris externa.
L. m. i.	Lamina medullaris interna.
L. m. v.	Lamina medullaris ventralis.
L. N.	Locus niger.
L. T.	Lamina terminalis.
Mass. Int.	Massa intermedia.
N. A.	Nucleus anterior thalami.
N. Am.	Nucleus amygdalæ.
N. Amb.	Nucleus ambiguus.
N. B.	Nucleus Bechterew.
N. C.	Nucleus caudatus (caput).
N. C^1.	Nucleus caudatus (cauda).
N. C. R.	Nucleus corporis restiformis.
N. Cu.	Nucleus cuneatus.
N. Gr.	Nucleus gracilis.
N. D.	Nucleus Deiters.
N. D. T.	Nucleus dorsalis tegmenti.
N. f. l. d.	Nucleus fasciculi longitudinalis medialis.
N. L.	Nucleus lateralis thalami.
N. M.	Nucleus medialis thalami.
N. Pf.	Nucleus parafascicularis thalami.
N. R.	Nucleus ruber.
N. Sl.	Nucleus semilunaris thalami.
N. Sm.	Nucleus submedialis thalami.
N. V.	Nucleus ventralis thalami.
N. V. gr.	Nucleus ventralis griseæ centralis.
N. V. T.	Nucleus ventralis tegmenti.

O. acc.	Oliva accessoria.
O. F.	Operculum frontale.
Oi.	Oliva inferior.
O. T.	Operculum temporale.
P. C.	Pedunculus cerebri.
Pc. i.	Corpus restiforme.
P. c. m.	Brachium pontis.
P. c. s.	Brachium conjunctivum cerebelli.
Pl. ch.	Plexus choroideus.
Pons.	Pons Varolii.
P. P. C.	Pes pedunculi cerebri.
Pulv.	Pulvinar thalami.
Pul. l.	Pulvinar lateralis thalami.
Pul. m.	Pulvinar medialis thalami.
Put.	Putamen.
Py^1.	Tractus pyramidalis.
Py^1X.	Decussatio pyramidum.
R. O.	Radiatio occipito-thalamica.
R. sp.	Tractus rubro-spinalis.
S. g.	Substantia gelatinosa.
S. L.	Septum pellucidum.
S. R.	Substantia Rolandi.
S. rt.	Substantia reticularis.
Str. t.	Stria terminalis.
Str. z.	Stratum zonale.
Sub.	Subiculum.
T. Ac.	Tuberculum acusticum.
Tap.	Tapetum.
T. C.	Tuber cinereum.
T. O.	Trigonum olfactorium.
Tr. cent. teg.	Tractus centralis tegmenti.
T. So.	Tractus solitarius.
T. sp.	Tractus tecto-spinalis.
t. th.	Tænia thalami.
V. A.	Fasciculus thalamo-mamillaris (Vicq. d'Azyr).
V. L.	Ventriculus lateralis.
Vn. III.	Ventriculus tertius.
Vn. IV.	Ventriculus quartus.
Vn. V.	Ventriculus quintus.
Z. i.	Zona incerta.
Z. r.	Zona reticularis.